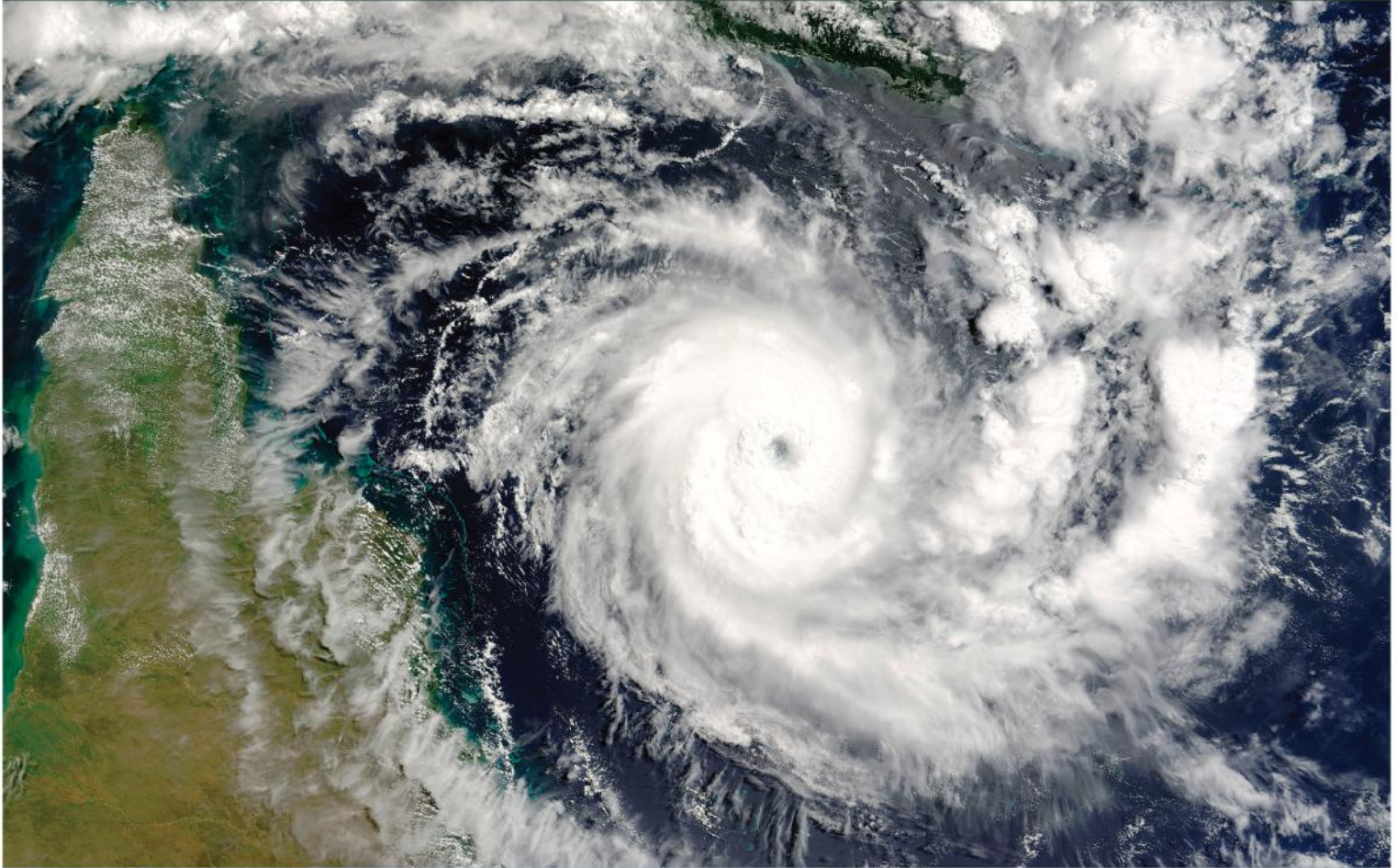




WET TROPICS
NRM CLUSTER

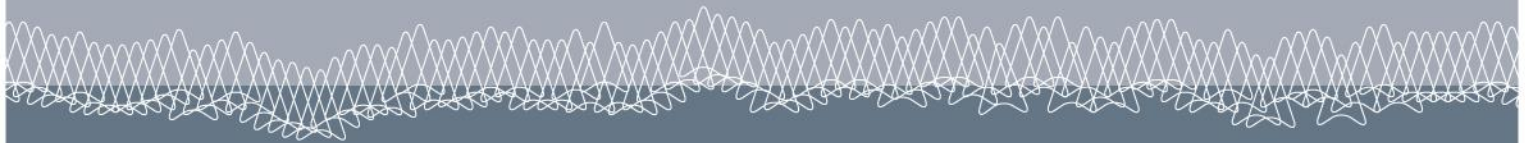


IMPACTS & ADAPTATION
I N F O R M A T I O N
FOR AUSTRALIA'S NRM REGIONS



Adaptation Pathways and Opportunities for the Wet Tropics NRM Cluster region

Volume 1. Introduction, Biodiversity and Ecosystem services



Edited by Catherine Moran, Stephen M. Turton and Rosemary Hill

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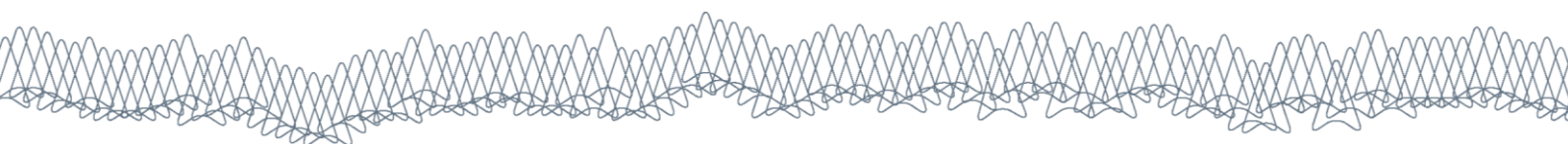


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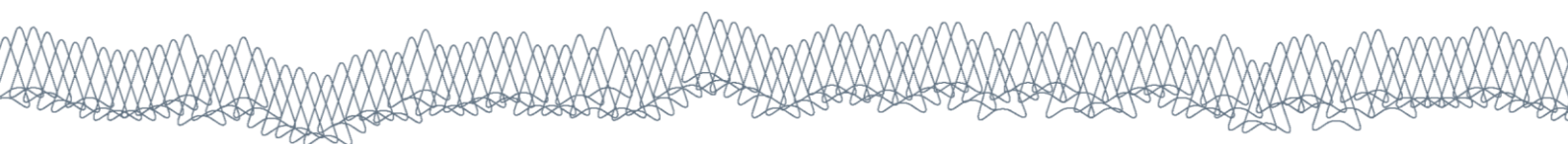
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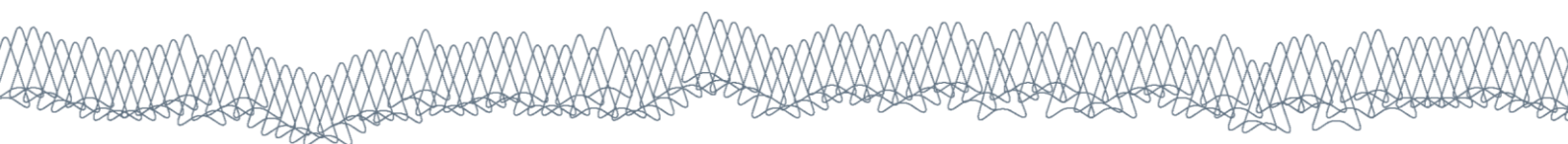
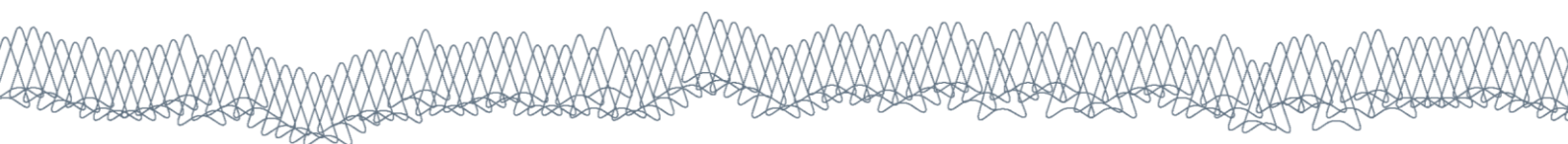


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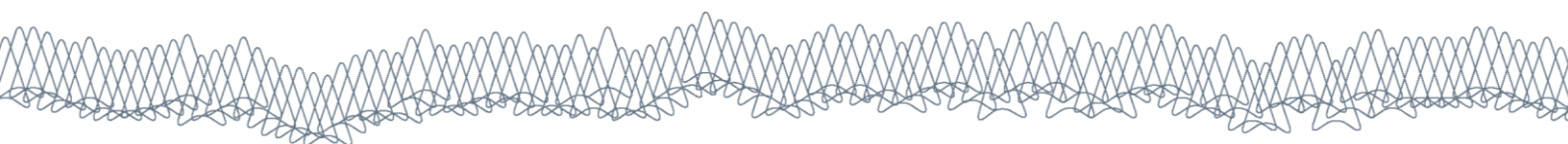
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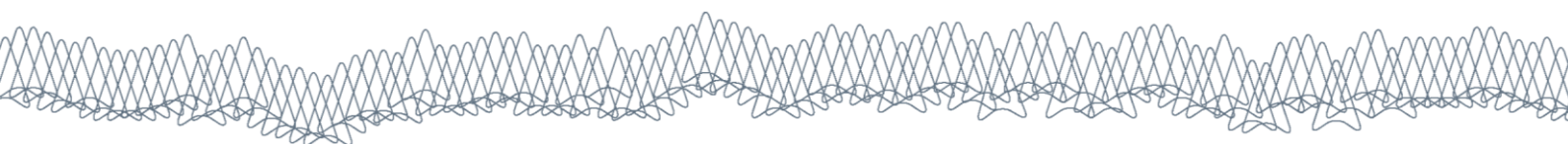
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Executive Summary

This report presents information intended to assist discussions about planning for adaptation to the impacts of climate change in the Wet Tropics NRM Cluster (WTC) region. It is clear that impacts of climate change are already being felt and that there will be unavoidable impacts even with immediate mitigation of greenhouse gas emissions. Continued high levels of greenhouse gas emissions will cause exceptional rates and scales of change in the future, and adaptation across all sectors of society will be inevitable. Planned adaptation will have better outcomes for communities than ad hoc, reactive responses, which would most likely be triggered by catastrophic events.

Transformational change will be required to adapt to predicted climate change impacts. We will need to undergo fundamental shifts in how we perceive and manage for biodiversity conservation, how we value ecosystem services, where we live and operate in the landscape, our agricultural products and practices, the ways in which we engage with Indigenous people and promote sustainable development in Indigenous communities, how we develop community adaptive capacity, engagement between science and policy, and how we plan. Strong support from all levels of government will be required and mitigation of greenhouse gas emissions will be critical. However, community-based, participatory planning processes can proactively build the capacity of communities to respond and adapt to climate change impacts. Regional Natural Resource Management (NRM) bodies are leaders in this process and have the capability and responsibility to negotiate pathways to adaptation that integrate ecological, social, cultural and economic aspirations of their communities.

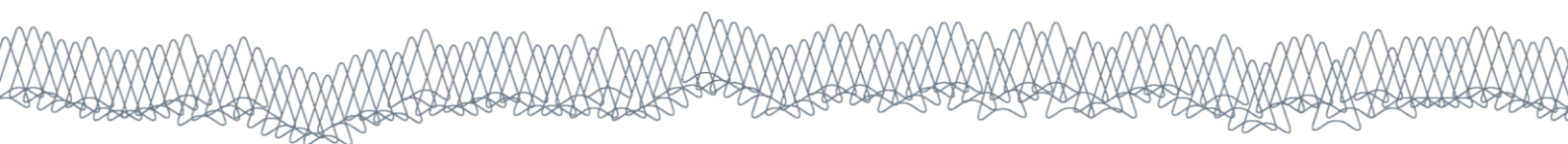
Successful adaptation to climate change will depend on the ability to detect and make changes in response to environmental, economic and social feedbacks, rather than maintaining usual practices. The implementation of individual actions that will cumulatively lead to adaptation at regional scales requires strategic planning. On-going collaborative partnerships between researchers and NRMs will improve vision-setting, strategy development and monitoring of outcomes. Integration with other relevant planning agencies and regulatory processes to commit to implementation

priorities will improve the ability of NRM plans to deliver effective adaptation outcomes for communities. Effective monitoring and evaluation of actions within an adaptive planning/ management framework will be essential to implementing effective adaptation pathways.

While climate change will impact all sectors, communities and industries that are dependent on natural resources will be particularly vulnerable. In the WTC region, this includes the primary industries and tourism, and Indigenous people. Climate change impacts in many Indigenous communities in the WTC are compounded by pervasive issues of justice and well-being resulting from historical disadvantage, as well as by the remoteness and challenging environmental conditions associated with many communities.

There is variation among sectors of the NRM community in terms of their capacity for resilience in the face of climate change impacts. For example, some individuals and certain sectors of the primary industries show a well-developed ability to respond to changes in environmental and economic conditions, whereas this adaptive capacity is low in other parts of the industry. There will be benefits for businesses that undertake early, proactive and planned adaptation. Many of the adaptation opportunities for the farming sector are consistent with current 'best practice' and won't require radical changes, although diversification into new products will likely be important. Ecosystem-based fisheries management has potential as a key adaptive strategy in this industry. Climate adaptation for mining will require addressing more significant site-specific challenges. Provision of information, research and development linkages and development of community support networks can increase the adaptive capacity of the primary industries.

Indigenous people have an inherently high capacity for resilience through their traditional, adaptive knowledge systems. There will be different suitable adaptation pathways for different Indigenous people, communities and groups. Continued formal involvement in the development of NRM strategies, improved land tenure security, governance and technical skills can contribute to the formulation of successful adaptation pathways.



Natural systems in general have low adaptive capacity and there will be unavoidable losses with projected climate change. Triggers and thresholds are almost impossible to determine, but eight of the ten Australian ecosystems that are considered to be most vulnerable to tipping points are located within the WTC region. Adaptation options for biodiversity conservation are broadly consistent with many current management strategies and managing to reduce existing threats and stressors will improve the capacity of species to adapt to climate change. However, climate change introduces additional threats that will require fundamental shifts in approaches to conservation. For example, focus will need to shift from protecting ecosystems in their current states to enabling their adaptation to altered conditions. In addition to protection, restoration will be a critical part of climate change adaptation strategies for biodiversity. Biodiverse carbon plantings have the potential to help mitigate CO₂, increase functional connectivity and increase the amount of good quality habitat available in the landscape. Fire management that accommodates changed environmental conditions will be an important part of enabling species' adaptation to climate change, as well as managing invasive species. The protection and rehabilitation of coral reefs will be critical. An appropriate system for payments for ecosystem services will support development of adaptation strategies that have cross-sectoral benefits.

Adaptation options for infrastructure include changing building design (e.g., elevation of infrastructure in low-lying coastal areas), reducing dependence on single modes of infrastructure (e.g., developing localised power generation and supply networks), and developing new industries (e.g., salt-tolerant agricultural crops) and technologies (e.g., water storage solutions). Retreat options for infrastructure involve relocation from impacted areas. Strategies of retreat currently have less political support in general, but will eventually become inevitable under current trajectories of greenhouse gas emissions. Options to Protect infrastructure from climate change impacts generally involve engineering solutions (e.g., sea walls), many of which may be inconsistent with biodiversity conservation objectives.

Substantial barriers to adaptation currently exist. Prime among these are a pre-occupation with the perceived costs of adaptation, frequent shifts in related government policy, and ignorance, misinformation and scepticism in the general community. The capacity for transformational adaptation is constrained in particular by the uncertainty surrounding projected impacts. At least in the short to medium term, adaptation action is more likely to be incremental.

Rationale and scope

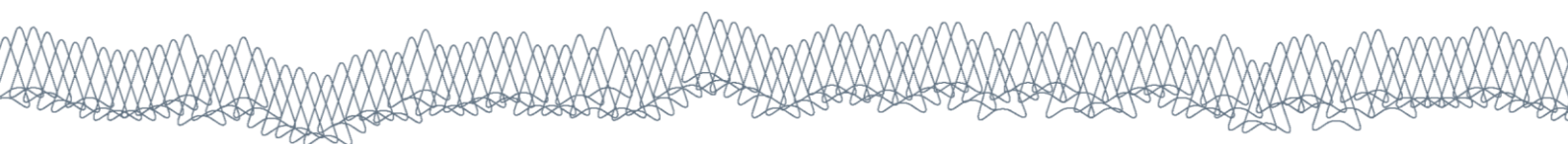
A previous report (Hilbert *et al.* 2014) outlined impacts of climate change in the WTC region, framed by the priority issues identified by NRM partners (Appendix A1). In this present report, authors have considered potential adaptation options in relation to these impacts, and included additional specific issues identified by NRM partners (Appendix A2). The report has undergone scientific peer-review as well as detailed review by WTC NRM partners.

This report reflects the range of ideas presented in scientific literature relating to adaptation options for different sectors. This report is not an exhaustive review of adaptation options, nor does it present integrated analysis of the ecological, social, cultural and economic costs and benefits of different adaptation options. Adaptation options will interact in complex ways among sectors. The priority and desirability of different adaptation options, together with trade-offs between competing objectives, will need to be negotiated with regional NRM communities. This report is intended to inform and support that negotiation process.

Catherine Moran, Stephen Turton, Rosemary Hill
Editors

Reference

Hilbert D.W. *et al.* (2014). *Climate change issues and impacts in the Wet Tropics NRM cluster region*. James Cook University, Cairns, Australia.
<https://publications.csiro.au/rpr/pub?list=ASE&pid=csiro:EP14913>



1. Introduction

Stephen M. Turton, Rosemary Hill and Catherine Moran

Stream 2 of the Commonwealth Government's *Regional NRM Planning for Climate Change Fund* supports the project "Knowledge to manage land and sea: A framework for the future" run by a consortium of scientists from James Cook University (JCU) and CSIRO. This report is the second major product of the consortium project, building on the first report: *Climate Change Issues and Impacts in the Wet Tropics NRM Cluster Region* (Hilbert *et al.* 2014). This second report provides syntheses of current knowledge about potential adaptation pathways and opportunities in response to climate change in the Wet Tropics Cluster (WTC) region (see below) across all relevant NRM sectors. The report is framed by the specific topics and issues defined by the NRM groups in the Wet Tropics Cluster (WTC) region (Appendix A), reflecting the planning processes and priorities of these groups as well as the characteristics of their regional communities. This report has two major aims:

1. To provide a review of potential adaptation pathways and opportunities across all NRM sectors in the WTC region, including a review of potential options for adaptation of species to climate change
2. To provide preliminary information about particular directions for adaptation in the Wet Tropics Cluster, based on collaboration with the four NRM bodies via the Brokering Hub.

For consistency with the first report, this report presents key messages around each topic in bold type at the beginning of each chapter. Key messages for NRM groups are also summarised at the beginning of each chapter. These key messages represent our syntheses of plausible adaptation pathways and opportunities based on expert opinion of authors and also substantiated by published material, including from international sources. Each key message is followed by a brief explanation of the underlying scientific evidence with a small number of key citations to the relevant literature. In most cases there is a fair amount of uncertainty associated with the key messages and they should be understood as best estimates based on the

scientific literature and expert opinion. Much uncertainty is due to climate model variability in relation to changes in rainfall amount and timing, critical variables for many NRM sectors in the WTC region. Furthermore, despite increasing climate change-related research in general, there is a limited or lack of explicit research on potential climate change impacts or adaptation opportunities in several areas and some sectors in the WTC region, e.g. infrastructure, ecosystem services and primary industries. Conversely, there is better knowledge of adaptation pathways for biodiversity in some parts of the region, although baseline data are lacking for many areas. Finally, uncertainty persists around the extent to which climate change impacts will be mitigated through reduction in greenhouse gas emissions, creating uncertainty around nature and extent of impacts and associated adaptation actions that will be required. NRM adaptation pathways also depend heavily on the broader set of adaptation options (or lack of) undertaken by the community and society at large.

This report contains ten chapters separated into two volumes. Volume 1 contains the executive summary, an introductory chapter and two chapters dealing with NRM adaptation pathways and opportunities for biodiversity and ecosystem services. Volume 2 contains chapters that discuss NRM adaptation pathways and opportunities for infrastructure, industry, Indigenous communities and broader regional society, as well as planning frameworks and evolving methodologies for developing adaptation pathways in NRM groups. In Chapters 2-5 we provide summary tables of specific adaptation options in relation to climate change risks, as identified within the body of these chapters. Remaining chapters deal more with higher-level principles or frameworks for climate change adaptation, or describe climate adaptation methodologies and tools, rather than identifying specific adaptation actions.

A range terms and phrases associated with climate adaptation are used throughout the documents. Authors have tried to explain these as necessary, but

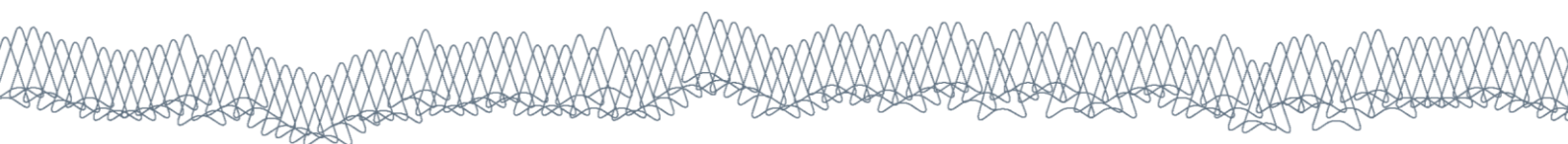


Table 1.1 provides a summary of key terms used in this report that may assist NRM planners.

Table 1.1 Definition of key terms used in this report.

KEY TERMS USED IN THE REPORT
1. Adaptation to climate change is the adjustment, in natural or human systems, in response to actual or expected climatic changes or their effects, which moderates harm or exploits beneficial opportunities. Various types of adaptation can be distinguished, including anticipatory, autonomous and planned adaptation.
2. Autonomous adaptation is adaptation that does not constitute a conscious response to climate stimuli but is triggered by ecological changes in natural systems and by market or welfare changes in human systems.
3. Vulnerability is defined as a function of the character, magnitude, and rate of climate change variation to which a system is exposed, its sensitivity, and its adaptive capacity.
4. Planned adaptation is adaptation that is the result of deliberate policy decision, based on awareness that conditions have changed or are about to change and that action is required to return to, maintain, or achieve a desired state. Planned adaptation measures are conscious policy options or response strategies, often multi-sectoral in nature, aimed at altering the adaptive capacity of systems by facilitating specific adaptations.
5. Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or cope with the consequences. Adaptive capacity of a system is its capacity to change in a way that makes it better equipped to deal with potential impacts.
6. Exposure is the degree, duration and/or extent to which a system is likely to be in contact with a perturbation e.g. cyclones, drought, fire. Defined as the external side of vulnerability. It is influenced by a combination of the probability and magnitude of climate change.
7. Sensitivity is the extent to which a human or natural system can absorb impacts without suffering long-term harm or other significant state change, i.e. an internal component of vulnerability. It is also defined as the

extent to which changes in climate will affect the system in its current form.
8. Resilience is the capacity of a system to absorb disturbance, undergo change and still retain essentially the same function, structure, identity, and feedbacks.
9. Incremental adaptation is adaptation actions where the central aim is to maintain the essence and integrity of a system or process at a given scale.
10. Maladaptation is actions or inaction that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change, or diminished welfare, now or in the future.

Source: Wilson & Turton 2011, IPCC 2014

Geographical scope

Australia's 56 NRM regions have been grouped into eight clusters through which funding for Element 2 of Stream 2 is delivered. The eight clusters are based on some broad common characteristics such as land use, climate and how these are anticipated to change (Figure 1.1). In total, Element 2 of Stream 2 is comprised of nine projects, one for each of the eight clusters, and a National Project delivering cross-boundary regional level information on issues that are national in scale, such as changes to biodiversity and invasive species resulting from climate change.

This report focuses on four geographically distinct NRM regions grouped in the Wet Tropics Cluster, shown in Figure 1.1. These are the Mackay-Whitsunday, Wet Tropics, Cape York, and the Torres Strait regions, which are managed by Reef Catchments NRM, Terrain NRM, Cape York NRM, and the Torres Strait Regional Authority respectively.

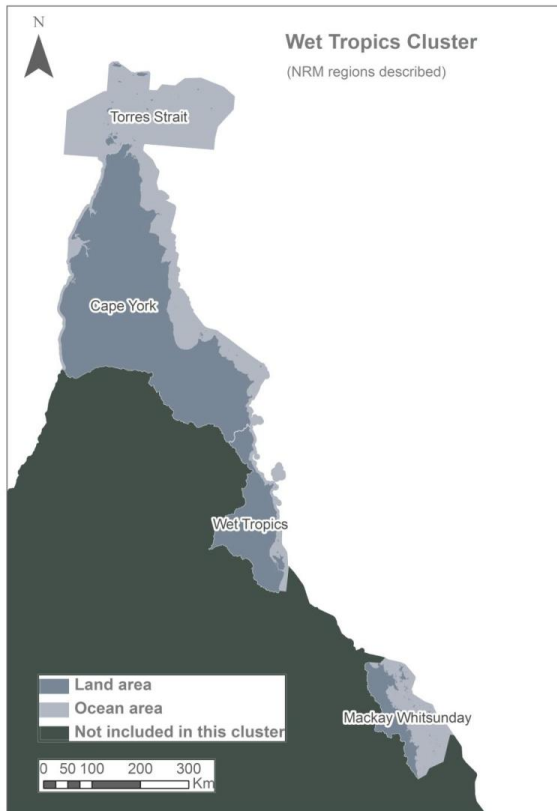


Figure 1.1 The Wet Tropics Cluster region (shaded).

Significance of the Wet Tropics Cluster Region

This cluster contains a broad range of landscapes and seascapes including globally significant savannas, the vast majority of Australia’s tropical rainforests, wetlands and low lying tropical islands. It also contains a high proportion of the Great Barrier Reef catchment. The region contains the Wet Tropics World Heritage Area and the Great Barrier Reef World Heritage Area with discussion for a third World Heritage Area nomination for parts of Cape York Peninsula. Arguably, this cluster supports more species overall than any other NRM cluster with many endemic plants and animals. Only the South West of Western Australia is richer in plant species.

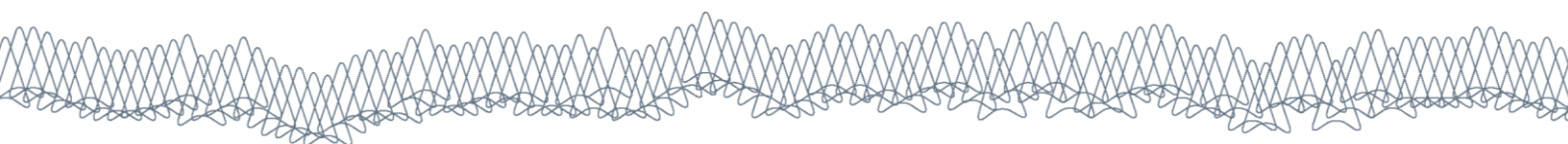
The climate change threat to biodiversity has been especially well documented for the Wet Tropics

rainforests (Hilbert *et al.* 2001; Kanowski 2001; Williams *et al.* 2003; Hilbert *et al.* 2004; Williams *et al.* 2008; Hilbert *et al.* 2014). While much of the cluster’s rainforest is in conservation reserves (especially the Wet Tropics World Heritage Area) some important areas are not, including many fragments and recovering forests on abandoned, previously cleared land. Management of off-reserve lands in response to climate change present both important opportunities and potential threats to biodiversity (Dunlop *et al.* 2012).

Along with very high biodiversity values, there are numerous and substantial economic and cultural values including extensive and intensive agriculture (McKeon *et al.* 2009, Biggs *et al.* 2013), tourism, mining, fisheries (Stoeckl & Stanley 2007) and large areas of Aboriginal lands. Much of the cluster’s area is ‘highly contested’ with multiple and sometimes conflicting demands for the region’s natural resources. Climate change is likely to exacerbate the issues and challenges. Climate change impacts and adaptation studies suggest significant changes in all sectors that will require factoring climate change into forward looking NRM planning across the cluster.

Both extensive and intensive primary production are likely to be challenged by climate change requiring adaptations in where, what and how food is produced in the region. The possible adaptation responses of this sector – as all others – will have important effects, positive or negative, on other sectors. There are adaptation opportunities provided by the Australian Government’s Direct Action Plan and Emissions Reduction fund (see Chapter 3, this report), that if managed properly, could assist climate adaptation in this sector while also favouring biodiversity conservation.

Traditional owners are important inhabitants and land managers in many areas of the cluster who are likely to be highly affected by climate change in numerous ways (see Chapter 6). The approximate proportion of Indigenous people is 50% in Cape York, more than 90% in the Torres Strait and 12% in the Wet Tropics. Indigenous people living in remote areas within this cluster have a high sensitivity to climate change induced ecosystem change because of the close connection for them between healthy ‘country’ and



their physical and mental well-being and their cultural practices (Green 2006). Other issues affecting their community's welfare are urgent and pressing and these will require strategies and policies to strengthen adaptation capacity of communities for climate-change responses (Petheram *et al.* 2010). Communities located on the low-lying islands of Torres Strait are particularly vulnerable to sea level rise and increasingly intense storm surges caused by more extreme weather (Green *et al.* 2009).

Natural resource management in the regions covered by this cluster has long been contentious due to its highly contested values in multiple sectors. The need for climate change adaptation in most of these sectors accentuates the challenge and requires an integrated approach.

Climate projections the Wet Tropics Cluster Region

The WTC region may expect significant changes in its climate this century and policy makers will need to incorporate the latest climate science knowledge and data into their adaptive management and planning systems. Table 1.2 provides a summary of climate projections for the WTC region over this century.

Table 1.2 Climate projections for the Wet Tropics Cluster region this century

CLIMATE PROJECTIONS FOR THE WTC REGION
<ul style="list-style-type: none"> • Air and ocean temperatures are expected to increase in response to increasing Greenhouse Gas (GHG) emissions • We can expect more hot days and fewer cold days in the future • There is considerable uncertainty about how climate change may affect rainfall across WTC region due to naturally high rainfall variability but with higher GHG emissions there is evidence that the dry season will be longer and drier while the wet season will remain similar • Extreme rainfall intensity may increase in the future • The intensity of tropical cyclones is likely to increase in the future while overall cyclone frequency may

decrease

- Sea levels should continue to rise but rates of change may vary at the sub-regional level
- Frequency and height of storm surges are expected to increase due a combination of rising sea levels and more intense tropical cyclones
- Fire weather conditions are expected to worsen with increased frequency or intensity of extreme fire days
- Solar radiation is expected to decrease in winter (dry season) and spring (wet season build up), and increase in autumn (monsoon retreat season) under the highest emission scenario; however there is a large spread of model simulations
- Small decreases in relative humidity are favoured over increases during summer and autumn periods, with little change in winter and increases more likely in spring, especially under the highest emission scenario
- Evapotranspiration is projected to increase in all seasons
- Average wind speeds are expected to increase across eastern parts of the WTC region
- Ocean acidity will increase in line with increases in atmospheric CO₂

Source: Turton 2014

Approach and method

A key component of the Stream 2 project was the adoption of a WTC 'Brokering Hub' which formally brings together Stream 2 researchers and NRM regional organisations (Cape York NRM, Reef Catchments, Terrain NRM and Torres Strait Regional Authority) to co-define priorities, objectives, processes, outputs and outcomes for the project, much like a project steering committee (Bohnet *et al.* 2013, Figure 1.2). This arrangement is intended to promote a collaborative approach to the research program and to facilitate communication between Streams 1 and 2. The collaboration moves through a co-research cycle that includes stages that provide for system analysis, processes and tools to support knowledge translation and integration, and updating through social learning (Figure 1.3). This report forms part of the socio-ecological systems analysis phase of the project and will feed in to the knowledge integration phase (Figure 1.3).

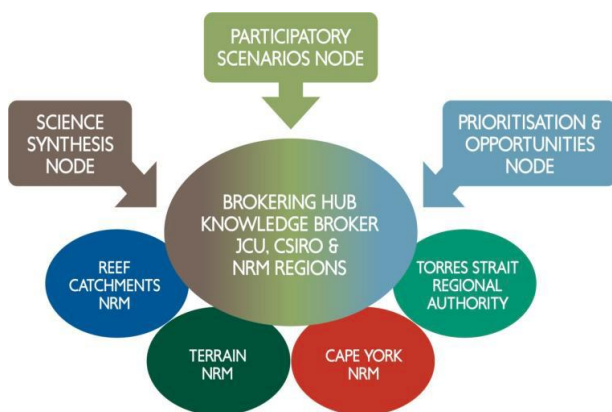


Figure 1.2 Co-research approach that promotes long-term system well-being and collective learning

Source: Bohnet *et al.* 2013

The Stream 2 research component of the Brokering Hub is divided into three ‘Science Nodes’ (Figure 1.2). The production of this draft report has been co-ordinated by the brokering hub, and researchers from all three Science Nodes have contributed, as well as NRM partners. NRM groups defined existing knowledge and priority information gaps through different processes; initially they convened a meeting to articulate their ‘preferred processes and priorities’ to inform the development of project bids by research consortia in the region when Stream 2 funding was announced in late 2012. The key issues of concern identified in this document formed the foundation for the science synthesis report (Hilbert *et al.* 2014). During 2013 and 2014, NRM groups in the WTC identified additional detail in relation to their information needs for NRM planning during two workshops, one a joint WTC-National Environmental Research Program (NERP) initiative and the other organised by the Participatory Scenarios Research Node. Finally, NRM groups were invited in November 2013 and March 2014 to clarify or add any further priority information needs. The current list of NRM priority information needs (Appendix A) for the current report reflect the issues NRM project partners expect will be important when engaging with their regional communities to develop adaptation pathways. NRM partners have requested discussion of high-level principles around approaches to adaptation and monitoring outcomes, presentation of case study

examples, identification of barriers and enablers, as well as information on a suite of specific issues. The list of NRM interests and concerns covers a wide range of issues in many sectors and experts in all of the fields identified were sought to contribute to the first science synthesis report and to this draft adaptation pathways and opportunities report. While this report is part of the system analysis stage of the co-research cycle, many knowledge integration tasks are underway through these interactions.

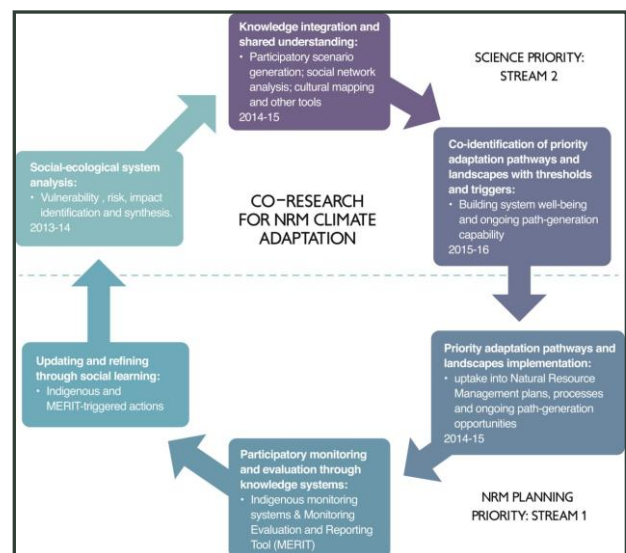
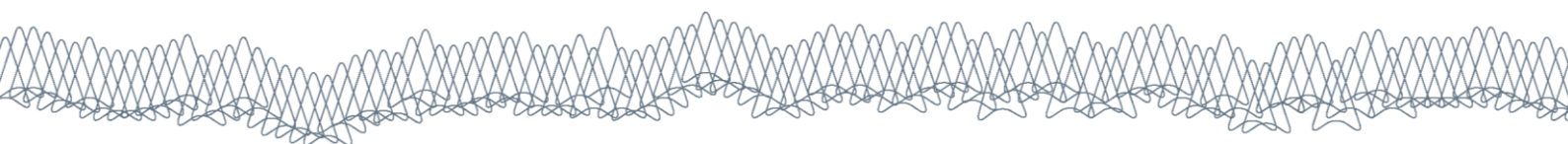


Figure 1.3 The co-research cycle for knowledge integration in NRM Climate Adaptation

Coping range, adaptive capacity and vulnerability

Among the different NRM sectors, natural and modified ecosystems have the lowest capacity to adapt to rapid climate change; even below 2°C temperature change – relative to 1990 - there will be significant negative effects on natural ecosystems (see Figure 1.4), due mainly to their narrow coping ranges. Development of adaptation strategies is a priority especially for natural ecosystems, agricultural systems, coastal communities and water security, all of which have relatively narrow coping ranges as well as adaptive capacity (Figure 1.4). Above 4°C of warming all NRM sectors will be highly



vulnerable and well beyond their adaptive capacity to cope.

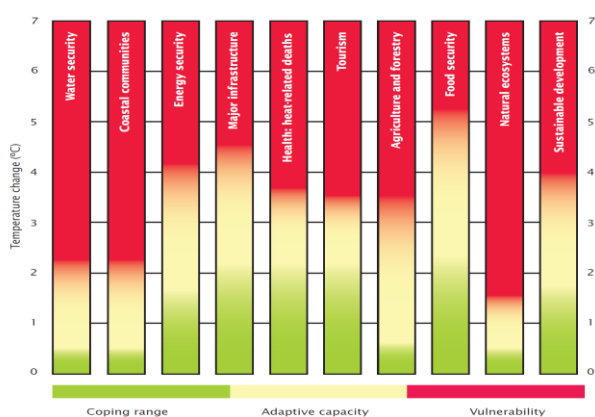


Figure 1.4 Figure shows the aggregated relative vulnerability to climate change for key sectors for Australia and New Zealand region. The vertical axis shows increasing levels of global mean temperature rise from 0 to 7°C, while the colours show how much change the sector can cope with normally (green), how much it can adapt to autonomously (yellow), and when it becomes vulnerable (red)

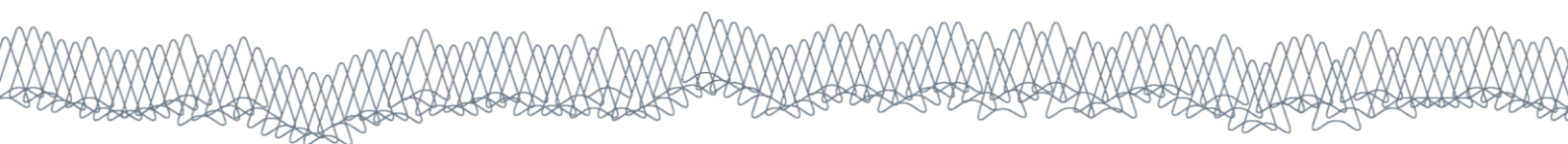
Source: Stafford Smith and Ash 2011

For successful climate adaptation in NRM, strong linkages are required among researchers, policy makers and practitioners because successful adaptation is the output of appropriate decision-making among all these actors. For example, policy makers can ensure that water and drought policies accord with successful farm adaptation and do not impede it. Researchers can help farmers to select suitable crop varieties, to achieve better water use efficiency measures, and to assist farmers to obtain the skills to achieve such outcomes (Howden *et al.* 2007; Stokes and Howden 2011).

As some uncertainties exist about the magnitude of impacts of climate change, making decisions about appropriate adaptation options is difficult (Stafford Smith *et al.* 2011). For example, decisions about water savings measures in consideration of drought conditions should be taken as soon as possible (Howden *et al.* 2007) but such decisions are difficult when trajectories are uncertain. Early development of technologies, skills and policies are likely to provide more benefits to the community (Stokes and Howden 2011).

A CSIRO survey of industry and government organisations found that Australians hold mixed attitudes to climate adaptation and this was linked with knowledge and beliefs of their particular organisation about climate change (Howden *et al.* 2007). They also found that industry organisations were more likely to undertake adaptation planning when it was perceived that their particular industry was vulnerable to climate change. It is therefore important to work closely with stakeholders to determine their vulnerability to climate change to better assist them to adapt to climate change. To obtain the benefits of climate adaptation stakeholders need confidence that the climate is changing and that inaction is not an option, the motivation to avoid negative impacts and seize opportunities, and wide communication and demonstration of new benefits of climate change adaptation (Stokes and Howden 2011). Therefore the very early part of adaptation is about conveying information to various NRM stakeholders why adaptation is needed and what are the perceivable opportunities of climate change and what are the risks of not doing anything. This task is already being undertaken by the WTC NRM groups; it is intended that this will be supported by outputs of the Stream 2 project (e.g., this and the previous impacts and issues synthesis report, together with associated fact sheets and short film), together with participation of Stream 2 researchers in NRM stakeholder workshops and other participatory processes.

The effectiveness of a community to adapt to climate change is influenced by the adaptive capacity of the respective community. Assessing the adaptive capacity of different stakeholders to climate change is crucial. Through assessment of adaptive capacity it is possible to determine and rectify the factors that may hinder the successful adaptations of a community and also to identify the broader areas where action is required (Stokes and Howden 2011). An assessment of adaptive capacity of different stakeholders of the WTC region will help policy makers and planners to take actions to increase the adaptive capacity of the stakeholders towards implementing successful climate adaptation.



Adaptation pathways and opportunities

Adaptation to climate change will engage all of society, including industry sectors, communities and individuals (Stafford Smith and Ash 2011). Domains that are emerging as key priorities for natural resource management and planning are:

- infrastructure, including roads, ports, coastal structures, water and energy supplies and buildings
- coastal zones, estuaries, wetlands and all areas at risk of sea-level rise, storm surges and floods
- agriculture, the food supply, and other primary production, including forestry and mining
- other climate-dependent industries, e.g. tourism
- the natural environment, including all the biodiversity contained within it
- increased biosecurity risk
- recognising maladaptation across key NRM sectors.

Three areas are critical for successful adaptation to climate change (Stafford Smith and Ash 2011):

1. decision-making and choices, i.e. how to go about it
2. the development of specific solutions to climate challenges, i.e. technical and other
3. the analysis of barriers to adoption of systems and technologies that will help us adapt.

Opportunities and threats are both components of adaptation to climate change. In the first science synthesis report (Hilbert *et al.* 2014) we identified key climate change threats to the various NRM sectors in the WTC region. We also need to identify the potential opportunities that may come our way due to climate change but with an understanding that there may be few opportunities in the WTC region (Stafford Smith and Ash 2011). These include:

- ‘no-regrets’ or low regrets measures, i.e. things we can do which make good sense anyway, e.g. water and biodiversity conservation and carbon sequestration
- ‘win-win’ activities, where adapting to climate change generates new industries (e.g. renewable energy), income, employment or other desirable community outcomes, e.g. carbon sequestration.

If we are to build ‘pathways’ to adaptation we need to

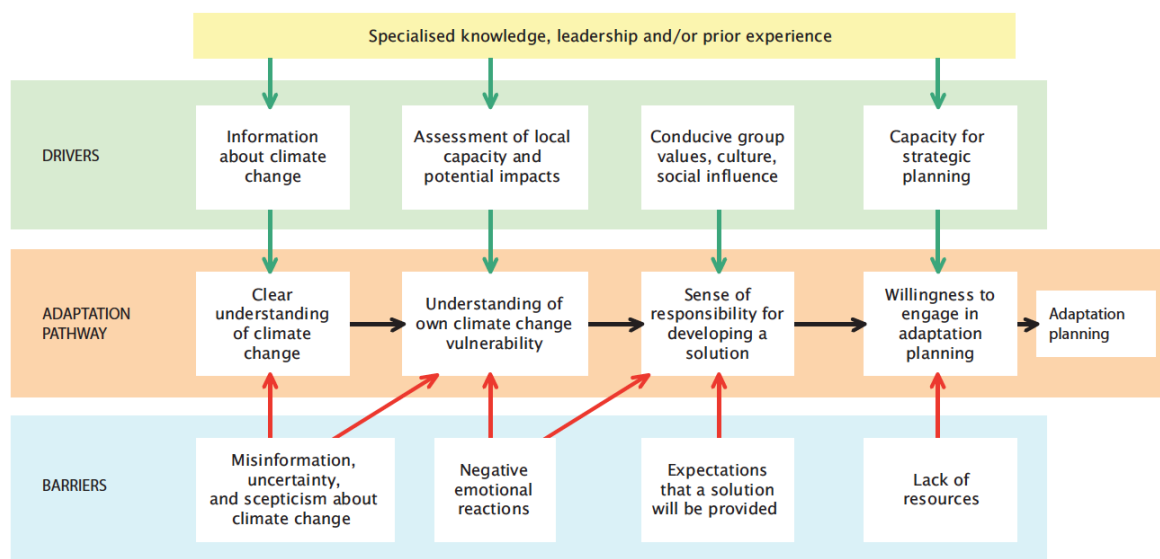
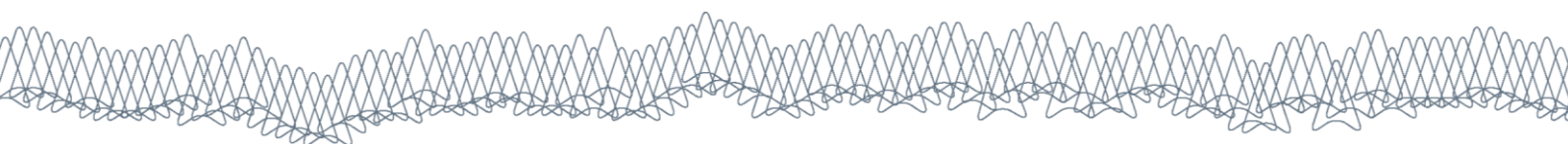


Figure 1.5 A pathway for adaptation engagement with associated drivers and barriers.

Source: Stafford Smith and Ash 2011



position our NRM sectors, regions and communities so that they are flexible and ready to change and this need to happen now (Stafford Smith and Ash 2011). This will require the knowledge and tools to build the necessary biophysical, social and institutional capacity to adapt to climate change. Figure 1.5 demonstrates the stages NRM communities or organisations are likely to transition through along an adaptation pathway, including identifying key drivers and barriers or obstacles to climate change adaptation. Recent studies also emphasise that actors have the capability to come together for path-generation in response to changed conditions in the future—building the conditions and skills for future path-generation is therefore important to adaptation futures (Garud *et al.* 2010).

Figure 1.5 is an example of a ‘classic’ adaptation

pathway where decision-making processes eventually leads to adaptation planning. Figure 1.6 conceptualises the classic adaptation pathway approach, incorporating a series of learning decision cycles over time (Wise *et al.* 2014). In this approach, some chains of decisions lead to maladaptive outcomes over time, but there may be other alternatives that are adaptive. The strongest colour shows a satisfactory pathway that can be plotted into the future.

Wise *et al.* (2014) argue that as the world seems increasingly likely to face a future with more than 2°C warming, it becomes increasingly important to move beyond impacts and vulnerabilities to adaptation action. Moreover, they propose that the classic view on pathways (Figure 1.6) does not always represent the decision contexts where the current status of the

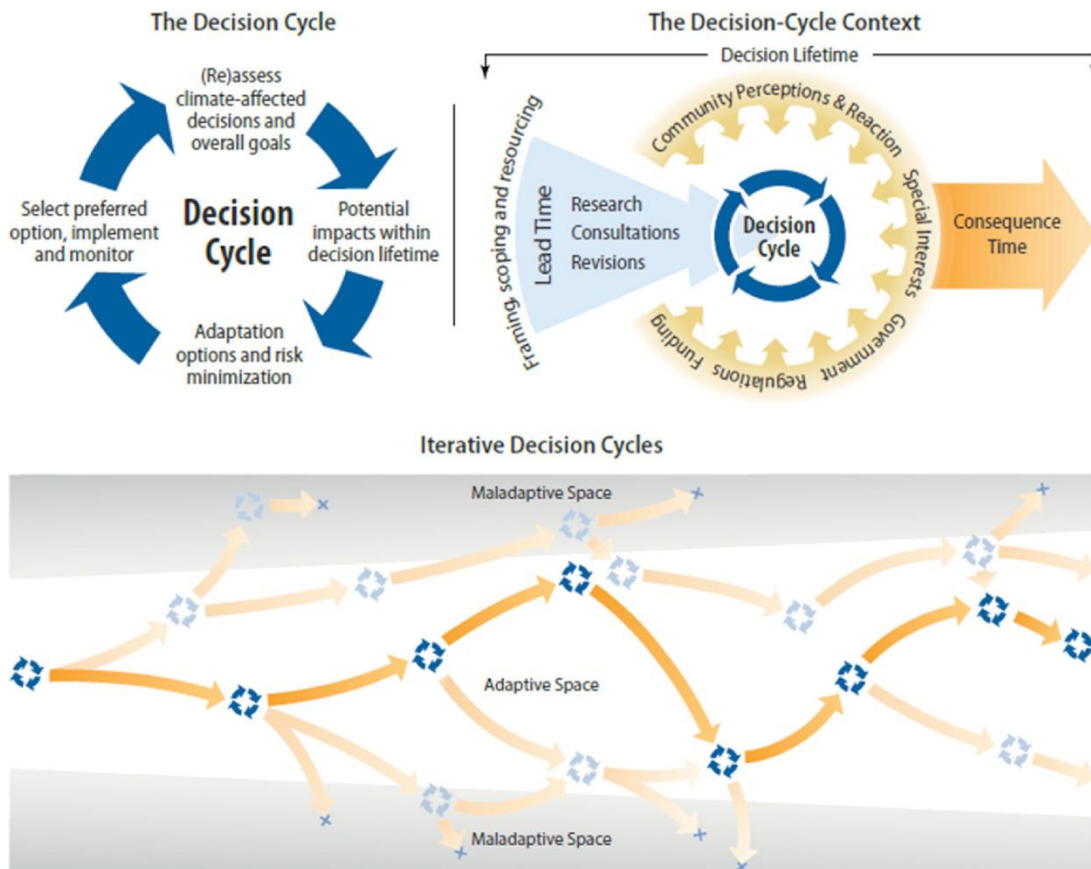
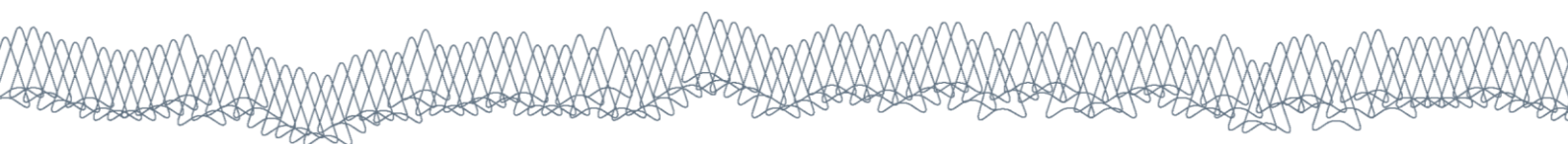


Figure 1.6. The ‘classic’ conceptualisation of climate adaptation pathways

Source: Wise *et al.* 2014



system and its future trajectory are heavily influenced by the past. Figure 1.7 provides a conceptual framework to trace 'adaptation pathways' through an adaptive landscape where the boundaries between adaptive and maladaptive responses are changing over time, due to biophysical changes, but also due to changes in social and institutional context, including the actions of other decision-makers who may perceive different adaptation pathways (Wise *et al.* 2014). Importantly, if decision-makers are not currently in the adaptive space (e.g. coastal local councils in the WTC region), as at decision point *b*, then all pathways may be maladaptive. For this example, transformation of the

institutional arrangements or societal values will be needed, either through dramatic intervention (*pathway 5*) or through strongly directed incremental change (*pathway 6*). Both pathways will require intervention from higher levels of governance, probably driven by responses to natural disasters or catastrophic events (Wise *et al.* 2014).

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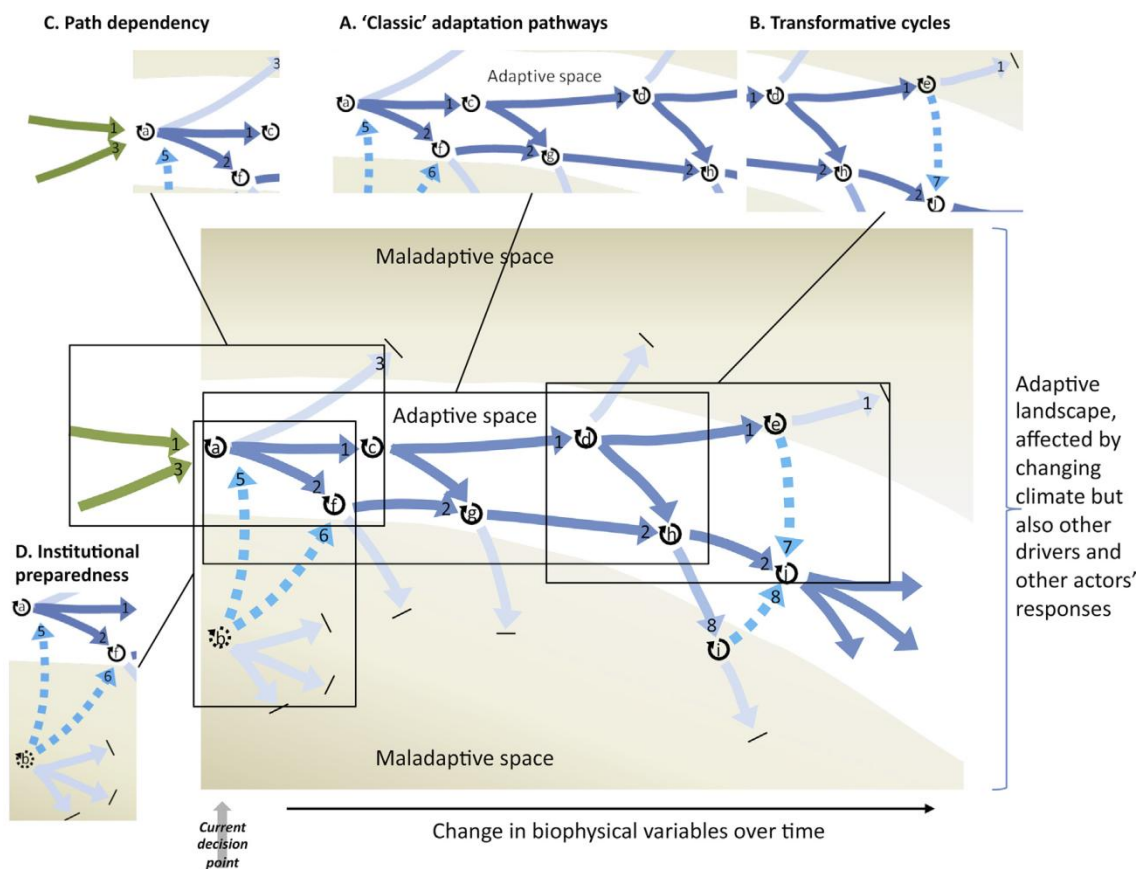
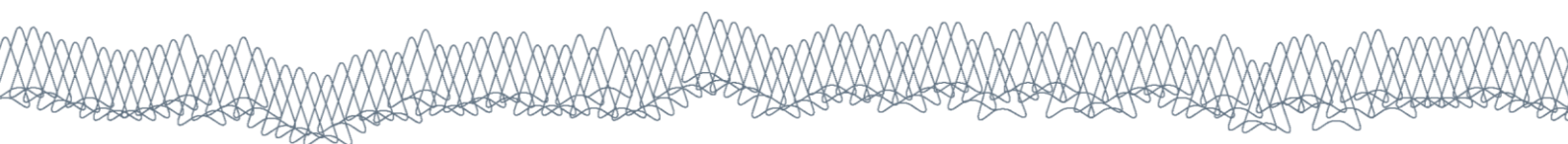


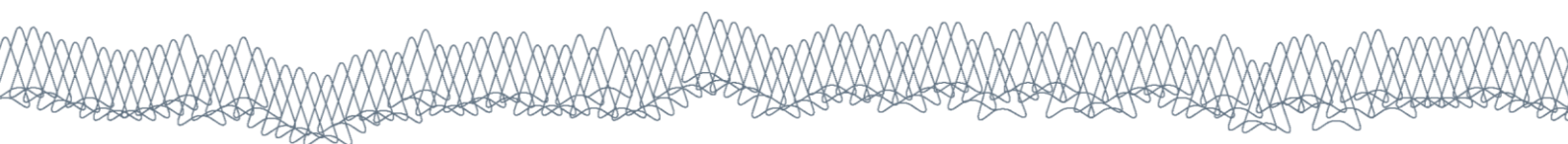
Figure 1.7. An adaptive landscape affected by changing climate, but also other drivers and other actors' responses. Circle arrows represent decision points (see Figure 1.6); dark blue arrows represent pathways that are contemporaneously adaptive; grey arrows lead to maladaptive dead-ends; dashed arrows represent more-or-less transformational pathway segments; and green arrows show antecedent pathways prior to the current decision cycle (*a*) faced by the decision-maker of concern.

Source: Wise *et al.* 2014



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2. Biodiversity – Adaptation pathways and opportunities

April E. Reside, Daniela M. Ceccarelli, Joanne L. Isaac, David W. Hilbert, Cath Moran, John Llewelyn, Stewart Macdonald, Conrad J. Hoskin, Petina Pert and Jennifer Parsons

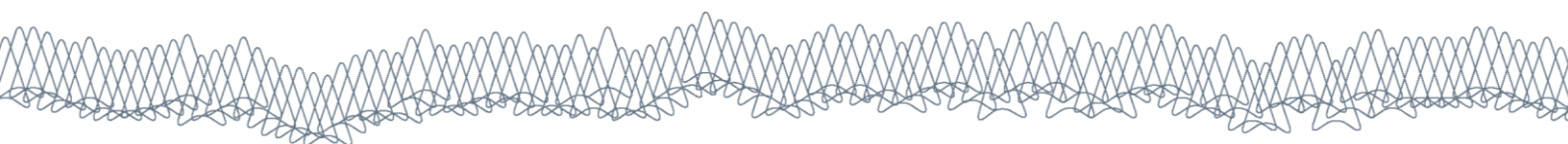
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- Impacts of climate change on biodiversity are already evident, and adaptation is required for the conservation of species and ecosystems. Managing to reduce current threats will improve the capacity of many species and ecosystems to adapt, but climate change introduces new and additional stressors that will require new conservation management approaches.
- As well as protection, restoration (e.g., reforestation, coral reef rehabilitation) will be a critical part of climate change adaptation for biodiversity conservation. Ex situ actions may be important for highly threatened species. Adapting fire regimes will be an important challenge as well as management tool.
- Successful adaptation management will require well-designed monitoring.

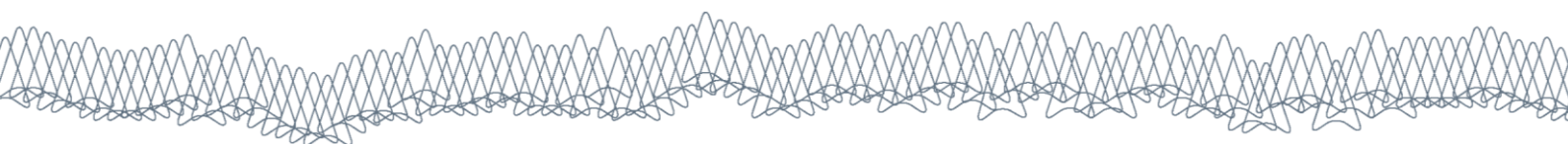
Precis

The possibilities, issues and barriers pertaining to the adaptation of biodiversity to climate change show similarities across the different ecosystem types, species and processes of the Wet Tropics Cluster (WTC) region. Many management actions for climate change are the same as those already known to be important to biodiversity management: reduce or eliminate other anthropogenic stressors in order to build integrity and resilience into natural systems and ideally assist them to withstand the future pressures associated with climate change. However, climate change will also involve different approaches in many respects including facilitating change, especially the movement of species and ecosystems as they track suitable climate and conditions. In addition, ‘in situ’ conservation – managing species in their habitat, or facilitating their dispersal within the landscape - will be less expensive than ‘ex situ’ conservation (managing species outside their current range). The key messages associated with each of the topics addressed in this chapter are:

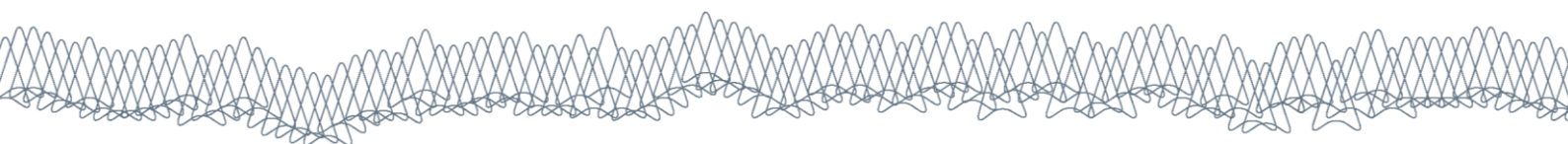
TOPIC	KEY MESSAGES
Introduction	<ol style="list-style-type: none"> 1. Successful biodiversity adaptation will be greatly constrained by the rate and ultimate degree of climate change. 2. Climate change is a different kind of threat to biodiversity so adaptation will require different approaches. 3. Effective adaptation strategies for biodiversity require awareness of the threat, reassessment of conservation objectives, and assessment of which conservation strategies will be most effective under climate change. 4. Adaptation and mitigation actions in the biodiversity sector will interact in complex ways with adaptation in other sectors.



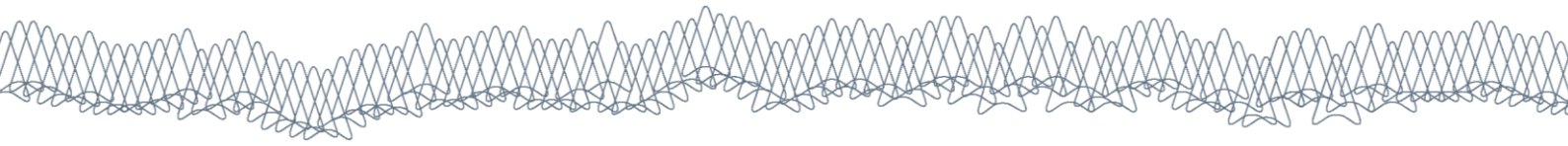
TOPIC	KEY MESSAGES
From maintaining ecosystems to enabling adaptation	5. As ecological communities change, it may become more important to identify key processes, communities or functional types that contribute to the persistence of an ecosystem, and focus on protecting those.
Conceptual and practical management options for conservation	6. Conservation planning is concerned with where, when and how to act to achieve conservation objectives. Climate change will prove a challenge to current conservation planning, bringing novel conditions, including novel ecosystems, extreme events and unprecedented rates of change.
Identifying and protecting key refugia	<p>7. Potentially the most cost-effective solution for biodiversity conservation under climate change is to identify and protect places in the landscape that will harbour many species from the worst impacts of climate change.</p> <p>8. Refugia need to safeguard long-term population viability.</p> <p>9. Refugia will need to be within the range of environmental parameters tolerable to species or ecological communities, or accessible if outside their current range.</p> <p>10. Ideal refugia will provide protection against multiple threats.</p> <p>11. Four different techniques used to identify refugia highlight the importance of the upland areas of the WTC Region as important refugia.</p> <p>12. The current protected areas encompass the areas that are known to be important for many species currently in the Australian Wet Tropics (AWT); however they are likely to miss the areas important for species in other parts of Australia that are likely to move into the AWT as a result of climate change.</p> <p>13. The southern upland rainforest of the AWT, particularly Hinchinbrook Island, Paluma Range and Mt Elliot, emerge as important refugia across all refugia analyses.</p> <p>14. The east coast of Australia has a high proportion of the area that will be climate change refugia when compared to the rest of Australia.</p> <p>15. The Australian Wet Tropics Bioregion is likely to be an important area for many species moving from the west and north.</p> <p>16. Adaptation for freshwater ecosystems must include the identification, protection and management of current and future refugia, especially in areas predicted to remain climatically relatively stable.</p> <p>17. The WTC region is expected to retain a large proportion of its freshwater biodiversity; therefore has conservation importance at a national level.</p> <p>18. Identifying refuges specific to freshwater biodiversity will require the consideration of refuge value, including abiotic factors, biotic factors, anthropogenic factors, spatial factors and temporal factors.</p> <p>19. Systematic conservation planning is an important tool for prioritising areas (e.g. refugia) for protection and restoration.</p> <p>20. Restoration will need to be a major part of climate adaptation.</p>



TOPIC	KEY MESSAGES
Translocation as a management tool	<p>21. Any translocation of species is highly risky, with high failure rates, even to a historically occupied site. The factors that determine the success of translocations include: removing threats, number of individuals translocated and the genetic diversity of the founding population. The success of translocations is species and situation-specific and many factors need to be considered.</p> <p>22. The facilitation of gene flow between populations through assisted interbreeding can be used to enhance the evolutionary potential of populations.</p> <p>23. Isolated populations on the periphery of a species' distribution may be adapted to the climatic conditions that will develop in core areas of the species' distribution as climate change proceeds.</p> <p>24. Facilitating gene flow between lineages and/or from peripheral isolates to core populations could bolster the evolutionary potential of populations in the WTC Region.</p>
Triggers and thresholds	<p>25. The uncertainty inherent in climate change predictions makes it almost impossible to determine set triggers or thresholds beyond which ecosystems are likely to change irrevocably.</p> <p>26. Previous studies that have identified environmental thresholds have highlighted that these are often specific to a particular location or time.</p> <p>27. Among the 10 Australian ecosystems considered most vulnerable to tipping points, eight occur in the WTC Region.</p>
Fire management	<p>28. Fire offers a number of opportunities for adaptation management, including prescribed burning of weedy flammable species and woody species encroaching on native grasslands. However, timing of burns will be critical to success in terms of biodiversity management.</p> <p>29. Fire management strategies will need to be adapted for different habitats and woodland types, and take into account faunal species within communities and previous seasons for fire management.</p>
Connectivity for movement and migration	<p>30. Adaptation efforts will need to be geared towards maintaining connectivity for assemblages to expand into new areas; impact minimisation or mitigation will need to target not just existing communities, but areas to the south (for tropical marine communities) and west (coastal communities).</p> <p>31. Increasing landscape connectivity is important for addressing conservation issues resulting from habitat fragmentation, and also for enabling shifts in species' distributions in response to climate change.</p> <p>32. The amount of good quality habitat in a landscape is positively related to degree of connectivity. Linear features may also be important, especially at smaller spatial scales.</p> <p>33. Many current projects are based on increasing connectivity at different spatial scales</p> <p>34. Cleared and modified parts of the landscape may contribute to functional connectivity.</p> <p>35. One of the risks of increasing connectivity is assisting dispersal of problem species or disease.</p> <p>36. Connectivity can be improved by integrated farm management that includes protection of remnant habitat isolated trees and areas of regrowth, managing dams and modifying fence design.</p> <p>37. Restoration, including biodiverse carbon plantings, may be able to increase connectivity in the landscape.</p>
Invasive species	<p>38. Existing invasive species threats should be controlled in order to increase the capacity of native biodiversity to adapt to climate change, and responses to climate change should not create new, or exacerbate existing, invasive species problems.</p>



TOPIC	KEY MESSAGES
Reproduction in vegetation communities	<p>39. Adaptation management actions will require a holistic approach, with the most cost-effective actions occurring for species in-situ. Ex-situ actions, for the most threatened species, may include seedbanking, genetic supplementation and/or assisted colonisation/dispersal and buyback of sites.</p> <p>40. The risks and benefits of adaptations should be taken into account, particularly with actions such as assisted gene flow. Seed-based risk assessment could be an option for some species from the WTC Region.</p> <p>41. Fire could be used as a management tool to promote seed germination in species adapted to a fire-prone landscape, with a 'sprouting' life-history strategy, but timing and frequency of burning should be considered on a case-by-case basis.</p>
Adaptation for important species and communities	<p>42. Adaptation options for marine turtles are mainly consistent with a reduction in other more immediate impacts.</p> <p>43. Protecting nesting beaches is the most cost-effective strategy of increasing turtle populations.</p> <p>44. A number of options exist to safeguard the most important nesting beaches from beach loss and inundation, effectively providing a buffer zone. Adaptation options will need to be tailored to individual beaches and the particular threats they face.</p> <p>45. Maintaining connectivity to suitable nesting habitat near existing nesting beaches, especially inland, will make a considerable difference to the capacity for nesting turtles to adapt to sea level rise.</p> <p>46. The identification and protection of turtle feeding grounds will also provide an important buffer to changing climate conditions.</p> <p>47. Reductions in direct mortality of turtles from boat strike, fisheries by-catch, plastic debris and disease must be controlled, and stranded turtle rehabilitation need to continue.</p> <p>48. Protecting dugong feeding habitat and reducing direct anthropogenic mortality should be the priorities of any adaptation program.</p> <p>49. Dugong mortality can be minimised through fishing closures, gear modification and boating restrictions.</p> <p>50. Creating protected areas achieves rehabilitation of coral reef systems.</p> <p>51. The benefits of restoring coral reefs currently outweigh the costs, except at very localised scales. Opportunities for improving restoration options should be considered, as this may be increasingly necessary in the future.</p> <p>52. Structural complexity is the most important restoration focus for coral reef communities.</p> <p>53. Identifying future refugia for coral reef organisms, or even whole coral reef communities, will be a crucial factor in assisting coral reef adaptation to climate change.</p> <p>54. Inshore reefs of the GBR are urgently in need of improved water quality management, both at the catchment scale and locally (e.g. around ports).</p> <p>55. Many of the required strategies for adapting to climate change in the Torres Strait will ultimately protect both human populations and ecosystems.</p> <p>56. For islands large enough to benefit from conservation actions, adaptation measures will be similar to those described for coastal assemblages turtles, dugongs, seagrass beds and coral reefs.</p> <p>57. Due to their flying large distances, adaptation strategies for flying-foxes will need to be considered</p>



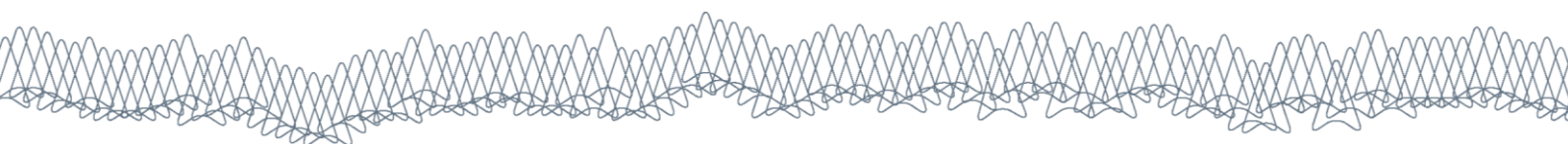
TOPIC	KEY MESSAGES
	<p>via a whole- landscape approach.</p> <p>58. The increasing urbanisation of flying-fox camps will need to be managed through public education and when non-lethal dispersals occur the impacts will need to be closely monitored.</p> <p>59. The greatest limiting factor for flying-fox persistence in the future is the quality and availability of food resources. Adaptation planning for these species should start with a good understanding of spatial and temporal resource distribution.</p> <p>60. Species-specific adaptation actions for birds will need to take into account life history and ecology, but general management to increase the adaptive capacity of the entire WTC Region will benefit a suite of species.</p> <p>61. The most important adaptation actions for birds will be managing current stressors, and in situ management including refugia identification and protection. Expensive ex situ options such as captive breeding and assisted migration should be considered a last option.</p> <p>62. Landscape connectivity will greatly improve the cassowary’s chances of survival.</p>
Monitoring adaptation outcomes	<p>63. Adaptation actions will require monitoring to ascertain whether they have produced desirable outcomes and to inform changes that may be required; ideally, monitoring should be embedded within an adaptive management framework.</p> <p>64. Monitoring programs should be initiated with a specific objective, or set of objectives, in mind.</p> <p>65. Monitoring should be embedded within a framework that involves scientists, management agencies, funding agencies and government.</p> <p>66. The power to detect changes depends on the sampling design, methods, timing and frequency of the monitoring program.</p> <p>67. Communication is the key link in all steps of embedding monitoring within an adaptive management framework.</p>
Summary and conclusions	<p>68. Ignorance and misinformation of the general public is a major obstacle at all levels, leading to disinterest and inertia, and supporting a continued lack of political will. Monetary cost is the most common perceived barrier to adaptation actions.</p> <p>69. Conservation messages fail to capture the role of market mechanisms in persuading the public and governing bodies of the benefit and urgency of climate change adaptation.</p>

Introduction

Successful biodiversity adaptation will be greatly constrained by the rate and ultimate degree of climate change.

The rate of climate change expected in this century is exceptional and climate modelling consistently demonstrates that global mean temperatures will become very high from the perspective of the past tens of millions of years if greenhouse gas emissions

continue to increase as they are now (IPCC 2013). Biodiversity is vulnerable to climate change, with limited intrinsic capacity to adapt to extremely high rates of rapid change. Even for warming of 2°C, there will be unavoidable loss of biodiversity, and predictions state that 4°C warming is quite likely without mitigation, with greater increases possible in the next century, if not sooner (Dunlop *et al.* 2012). So the efficacy of adaptation management plans and actions, while useful and important, are limited without adequate and timely reductions in emissions.



Climate change is a different kind of threat to biodiversity so adaptation will require different approaches.

Climate change is a fundamentally different threat to biodiversity than other current threats such as habitat reduction and fragmentation, inappropriate and unsustainable land use, feral animals or invasive weeds. Consequently, in addition to the ongoing management of other threats, management of climate change impacts or adaptation will require different approaches.

Dunlop *et al.* (2010) lists ways in which climate change is unique, including:

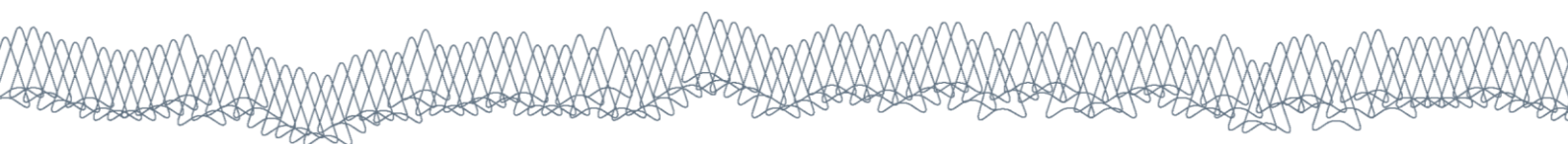
- Climate change will lead to many different types of changes to species and ecosystems; some of those may result in loss, others will not.
- The impacts of climate change will be experienced across all biodiversity and cannot be excluded in the way legal protection can reduce habitat loss or pest exclusion can reduce the impacts of invasive species.
- The rate, scale and geographic extent of climate change and the responses of biodiversity make this a phenomenon of a much greater magnitude than other threats.
- All biodiversity will be affected and change will be on-going for many decades, if not centuries, requiring a major revision of the objectives of development and conservation.
- It is likely that systematic management responses are needed, as opposed to addition of climate adaptation band-aids to existing portfolios of conservation strategies.
- There is considerable uncertainty about future environmental change, how biodiversity will respond, where the losses will be and what actions might reduce those losses. And there will be limited opportunity to reduce those uncertainties by learning from locations that experience the impacts first or from early signals since changes will be occurring everywhere and many changes will be hard to detect against the noise of environmental and ecological variation.

- While much ecological and evolutionary theory is predictive when only one or two factors are varying, the circumstances of climate change make accurate prediction from available theories very difficult. For example, contrasting predictions about change and vulnerability can frequently be made from different strands of ecological theory.

Effective adaptation strategies for biodiversity require awareness of the threat, reassessment of conservation objectives, and assessment of which conservation strategies will be most effective under climate change.

Dunlop *et al.* (2010) adapted suggestions in Van Ittersum (1998) to propose three steps for developing effective responses to the impacts of climate change.

1. There needs to be awareness and agreement that climate change will affect biodiversity and action is required. In regions where biodiversity decline is ongoing and significant due to other pressures (e.g. mammal decline in northern Australia), climate change adaptation may appear a lower priority. Likewise, it may appear in some regions that biodiversity will be resilient to climatic changes, or that little can be done about it. This step involves recognising that climate change will directly affect important biodiversity values and also affect the management of existing pressures.
2. Conservation objectives need to be reassessed in light of the likelihood of significant and continual future changes in species and ecosystems. Assessing the feasibility of different conservation goals involves understanding how the full spectrum of climate change impacts will affect a wide range of biodiversity values and how it may be possible to reduce future biodiversity losses by managing differently in response to climate change. In practice it is hard to move substantially beyond identifying additional monitoring and management actions that might help preserve currently threatened species or ecosystems at this stage of climate change. Future-oriented conservation strategies need to accommodate the likelihood of substantial changes in biodiversity at most locations. This step must include consideration of a wide range of types of change and values to be effective. The reassessment



of objectives should not to be bypassed in the haste to implement on ground action due to increasing sense of urgency.

3. Assess which conservation strategies will be most effective under climate change. This includes considering the revised conservation objectives, the availability of information, the effectiveness of different options, and the impact of uncertainty on outcomes and effectiveness. The types of strategies that are most suitable, and how species or locations are targeted, will depend on these factors.

To be effective and to promote adoption, adaptation strategies need to fit in with both local institutional and ecological contexts (Howden *et al.* 2007). The biodiversity chapter of the impacts report for the WTC Region (Hilbert *et al.* 2014) assists with step one by outlining the breadth and likely severity of the climate change threat. Step two will require a lengthy discussion among all stakeholders that is likely to be contentious and ongoing since it requires rethinking, perhaps radically, previous conservation paradigms. The third step, developing effective new conservation and adaptation strategies that address the new objectives will also be a lengthy process that might best be done through an adaptive management approach.

Adaptation and mitigation actions in the biodiversity sector will interact in complex ways with adaptation in other sectors.

The linkages between mitigation and adaptation are only beginning to be explored, but natural resource management is one of the areas with the greatest potential for synergies. Managing the trade-offs and promoting the synergies between adaptation and mitigation is likely to be important both in adaptation to climate change, and in limiting climate change to a level at which it is still possible to adapt (Campbell *et al.* 2009).

Ecosystem-based adaptation can be a cost-effective strategy to address the impacts of climate change, particularly in vulnerable areas where adaptive capacity is low (Campbell *et al.* 2009). For example, conserving coastal ecosystems can play a role in coastal protection and buffer the impacts of storms while maintaining fish breeding grounds; and help with climate change

mitigation through large carbon storage potential. Conversely, engineering solutions such as sea walls might have detrimental effects on coastal ecosystems (see Connectivity for Movement and Migration section below).

From maintaining ecosystems to enabling adaptation

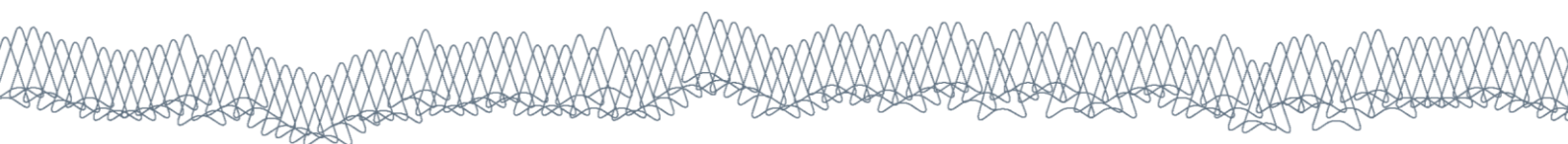
Historically, biodiversity conservation has emphasised the need to “protect” and “preserve” biodiversity, community structure, functional redundancy, ecosystem services and resilience; with the implication that the desire is to maintain current assemblages, communities and processes (Iwamura *et al.* 2010). However, given the predictions of species range shifts, and the fact that measured climatic changes have already surpassed predicted scenarios, this is unrealistic. Models of likely changes in suitable habitat for terrestrial, freshwater and marine species highlight areas that may serve as refugia in the future (See Refugia section below).

As ecological communities change, it may become more important to identify key processes, communities or functional types that contribute to the persistence of an ecosystem, and focus on protecting those.

Ecosystems are dynamic in nature, and change should be measured against an understanding of the background temporal and spatial dynamics in a system (Moritz and Agudo 2013a). Persistence of the whole ecosystem can rely on one or a few key species or processes that either build the habitat or maintain balance among the ecosystem components, often against a backdrop of periodic disturbances (Hedwall *et al.* 2013).

Hannah *et al.* (2002a) outlined five key elements for what they termed “climate change–integrated conservation strategies (CCS)”:

1. regional modelling of biodiversity response to climate change
2. systematic selection of protected areas with climate change as an integral selection factor



3. management of biodiversity across regional landscapes, including core protected areas and their surrounding matrix, with climate change as an explicit management parameter
4. mechanisms to support regional coordination of management, both across international borders and across the interface between park and non-park conservation areas
5. provision of resources, from countries with the greatest resources and greatest role in generating climate change to countries in which climate-change effects and biodiversity are highest.

Conceptual and practical management options for conservation

Conservation planning is concerned with where, when and how to act to achieve conservation objectives. Climate change will prove a challenge to current conservation planning, bringing novel conditions, including novel ecosystems, extreme events and unprecedented rates of change.

Under climate change, a static approach to ensuring the persistence and health of species and ecosystems within a conservation area will no longer be viable (e.g. Dawson *et al.* 2011). Management actions that safeguard species and ensure ecosystem persistence with changing conditions are considered no-regret or best practice strategies.

The evidence shows that species react idiosyncratically to climate change, and that species assemblages and ecological communities are likely to be different to the way they are now (Moritz and Agudo 2013b). Therefore, we use species as a conservation unit for much of the discussion in this chapter.

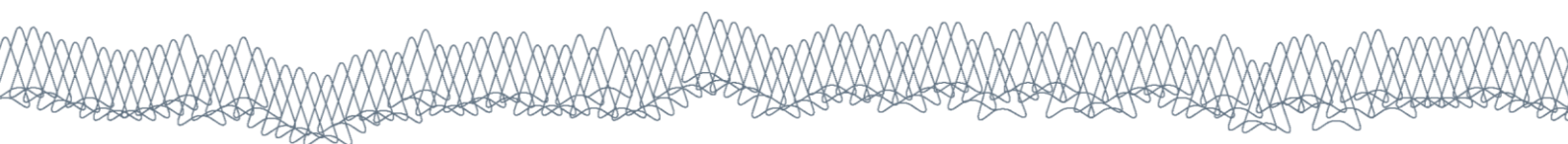
Garnett *et al.* (2013) identified adaptation strategies for multiple and single species and grouped them into three categories - immediate actions, ongoing actions and future action, for both inside a species' current range (in-situ) and outside a species' current range (ex-situ) (Table 2.1).

Table 2.1 Potential adaptation actions for ecosystems, communities and species

Adaptation action	IN-SITU	EX-SITU
Immediate Actions	<ul style="list-style-type: none"> • Modelling of climate change refugia • Species surveys • Baseline taxon management and research • Land management • Land purchase 	<ul style="list-style-type: none"> • Assisted colonisation or dispersal • Assisted gene flow
Ongoing Actions	<ul style="list-style-type: none"> • Monitoring • Species management • Maintain and improve habitat quality • Control current stressors – introduced pests, clearance, etc. • Land management • Land purchase 	<ul style="list-style-type: none"> • Captive breeding • Cryogenic seedbanking
Future Actions	<ul style="list-style-type: none"> • Establish new habitat • Feasibility study of potential management • Marine refugia modelling 	<ul style="list-style-type: none"> • Genetic supplementation • Assisted colonisation

Source: adapted from Garnett *et al.* (2013)

In-situ conservation is likely to be the most cost-effective way to increase adaptive capacity within a whole ecosystem, and suite of species including plants and fauna. However for the most endangered species, ex-situ actions, including captive breeding, re-introductions from botanic gardens or zoo populations, seedbanking, and assisted migration, could be a last, expensive, option to save the species in the wild



(Garnett *et al.* 2013, see sections on Genetic translocation in the Wet Tropics and Considerations for Translocating Species). We discuss a range of in-situ and ex-situ conservation strategies below.

Identifying and protecting key refugia

Potentially the most cost-effective solution for biodiversity conservation under climate change is to identify and protect places in the landscape that will harbour many species from the worst impacts of climate change.

The effect of climate change will not be experienced equally in all places because local weather systems and landscape features can act to amplify or dampen global patterns. By identifying parts of the landscape where species can retreat to and persist during the coming century (the timeline in which we can model); e.g. ‘refugia’, we are in an informed position to minimise biodiversity loss through management of these key areas (Reside *et al.* 2013). Currently “refugia” is used to refer to areas large enough to support populations of species under changing climatic conditions (evolutionary timescales), while “refuges” shelter individuals from short-term disturbances (ecological timescales) (Ashcroft 2010; Keppel *et al.* 2012).

Considerations for identifying terrestrial refugia

Refugia will be important for species persistence if they provide protection from climate change, safeguard long-term population viability and evolutionary processes and minimise the potential for deleterious species interactions. However, refugia can only provide these protections if they are available and accessible to species under threat.

Refugia need to safeguard long-term population viability.

For refugia to safeguard evolutionary processes, areas need to be large enough to sustain populations without erosion of genetic diversity (Ovaskainen 2002), and

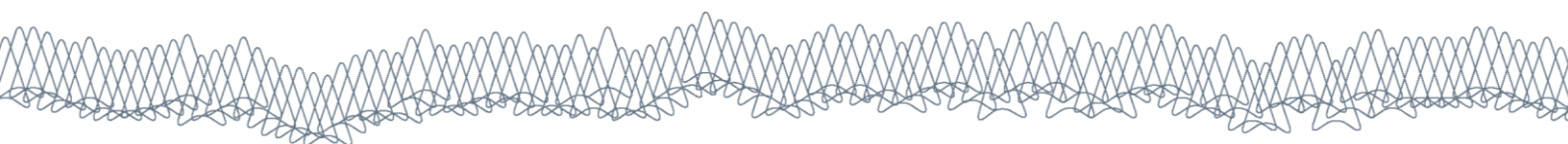
networks should capture a sufficient range of habitats and areas to maintain within-species genetic diversity (Reside *et al.* 2014). This would enable the maintenance of longer-term evolutionary processes, such as speciation and lineage sorting. A focus on identifying refugia for vertebrates is likely to capture areas that will act as refugia for invertebrates and many plants (subject to proximity constraints) (Moritz *et al.* 2001). Minimum refugium size will also depend on site-based factors such as latitude, productivity and environmental heterogeneity. However, overall larger refugia, and networks of refugia, have a higher likelihood of maintaining viable populations of many species (Ovaskainen 2002).

Refugia will need to be within the range of environmental parameters tolerable to species or ecological communities, or accessible if outside their current range.

Refugia within the area the species currently occurs are the most beneficial because fewer range shifts are required. The ability of a species to reach refugia outside its current range will depend on the distance from the current species’ range, the dispersal ability of the species, the conditions in the intervening habitat (i.e., can individuals survive and reproduce), and whether or not there are any physical barriers to dispersal (e.g., rivers, mountain ranges). Factors such as competition from existing species may prevent arriving species from establishing.

Refugia availability is influenced by landscape position and structure. High topographic variability can reduce the distance a species is required to move to track its climatic envelope (Tzedakis *et al.* 2002). However, the reverse is true for species already confined to mountain tops; in which case the nearest refugia may be at higher latitudes with intervening lowlands creating a dispersal barrier (Anderson *et al.* 2012). There may be similar barriers for coastal or lowland species (see below). Connectivity of habitats throughout the landscape will be important for facilitating species movement.

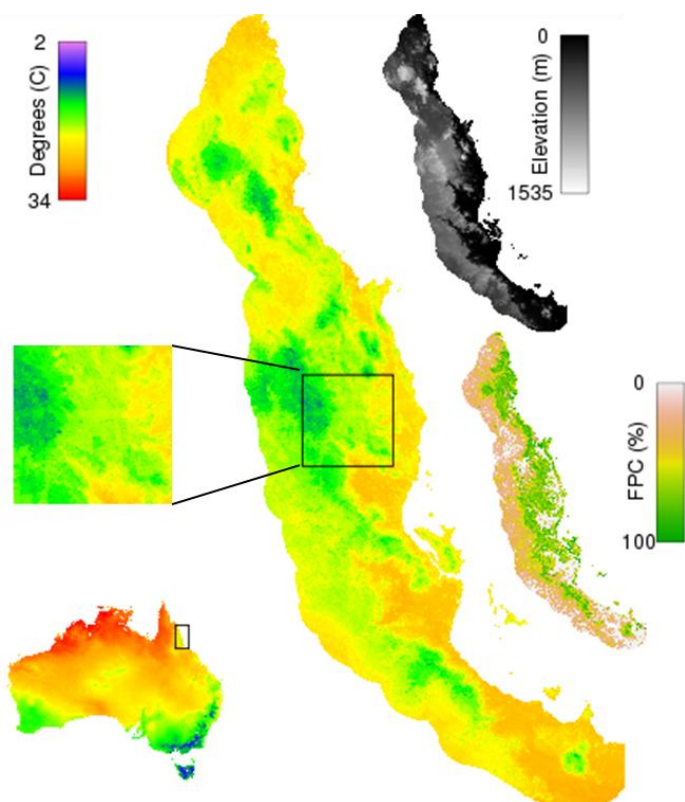
Ideal refugia will provide protection against multiple threats.



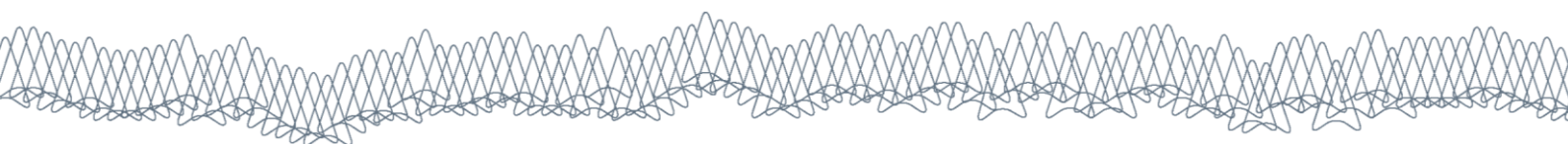
Many locations can provide refugia from more than one climate change-related threat (Reside *et al.* 2014). In particular, the synergies between thermal, hydric and fire processes mean that refugia will often protect species from changes in these processes simultaneously (Figure 2.1). Areas of hydric refugia (e.g., streams, riparian zones) are often cooler (Dobrowski 2011) and less fire-prone than the surrounds as a result of riparian vegetation supported by the available water (Woinarski *et al.* 2000). Areas protected from direct sunlight have less evaporation and often less flammable material (Couper and Hoskin 2008). Mountains and rocky gorges provide thermal, mesic and fire refugia through physical barriers to radiation and fire; also water accumulation and subsequently less-flammable vegetation. Mountains also provide refugia from cyclones through protection from wind.

WTC Region as important refugia.

Four different techniques used to identify refugia highlight the importance of the upland areas of the



*Figure 2.1 High-complexity areas can offer multiple refugial properties. The thermal gradient of a daily maximum temperature in a mountainous region: the Australian Wet Tropics (AWT). High temperatures indicated by warmer colours on the continental and regional maps. This rugged area provides thermal, hydric, and fire refugial properties at both local and continental scales. The upland areas are cooler than their surrounds, and generate substantial orographic rainfall; this in turn promotes the growth of rainforest communities and the suppression of fire. Additional refugial properties are generated by steep gullies (which may protect against cyclonic events and strengthen the hydric refugial properties of the region). Data shown is at a 250 m resolution, adapted from Storlie *et al.* (2013) and Reside *et al.* (2014). The large AWT is the temperature gradient, shown in detail in the middle left square insert. The top small AWT is the elevation gradient, and the bottom small AWT is foliage projective cover, with green the more vegetated areas.*



An Australia-wide analysis was conducted via funding from the National Climate Change Adaptation Research Facility to identify the most likely areas for terrestrial (Reside *et al.* 2013) and freshwater (James *et al.* 2013) refugia. The terrestrial refugia analysis was composed of several different techniques:

1. Species distribution modelling, looking at areas of species richness current and projected into the future (Figure 2.2a)
2. Composition turnover modelling which uses topographically adjusted radiation, climate and moisture surfaces at 250m resolution across Australia to show areas where species would have to move the least in time and space to remain in suitable conditions (Figure 2.2b),.
3. The locations of current species- and lineage-level diversity for rainforest-endemic lizards that are likely to represent long term stability in conditions (Figure 2.2c)
4. Finally, a conservation-planning exercise

incorporating measures of irreplaceability and complementarity, based on endemic rainforest vertebrates of the Australian Wet Tropics (AWT) bioregion (Figure 2.2d).

Analyses 1, 2 and 3 all extend beyond the AWT, however, the comparison for this region was made because each of these analyses did occur across this region (Reside *et al.* 2013).

The comparison shows that while there are some differences, there is good spatial congruence for the important refugia areas. In particular, the refugial value of the upland areas in the north (Carbine, Windsor, Thornton), central (Bellenden-Ker/Bartle-Frere, Lamb and Herberton ranges) and south (Spec and Elliot) are all represented by each of the four analyses. These upland areas are recognised as being of conservation importance, centres of evolution and containing endemic species (Williams 1996).

The current protected areas encompass the areas that

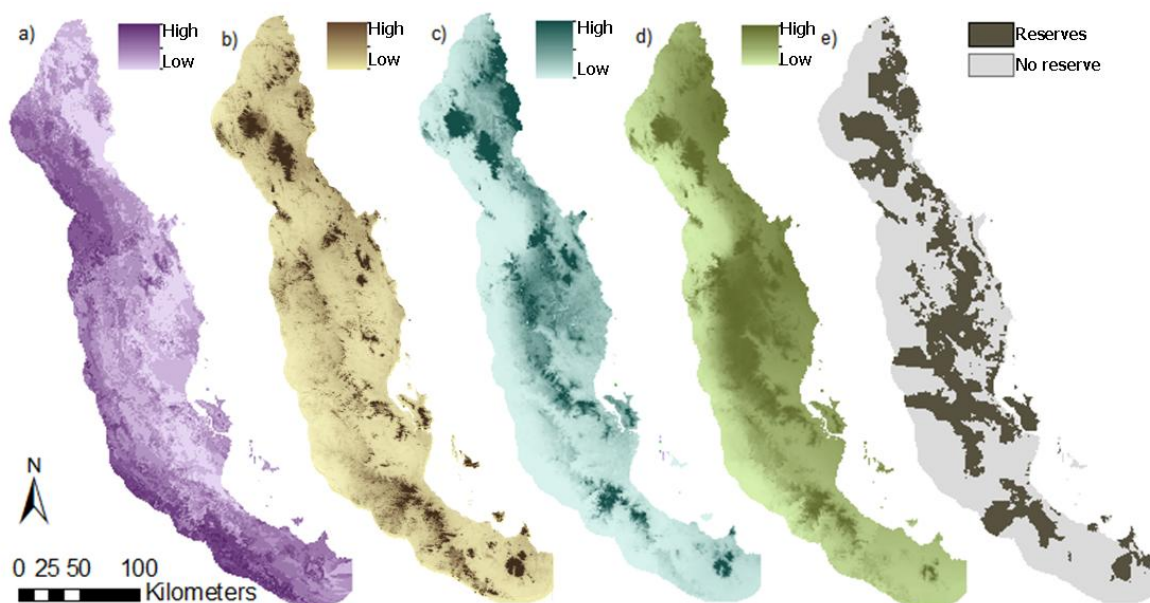
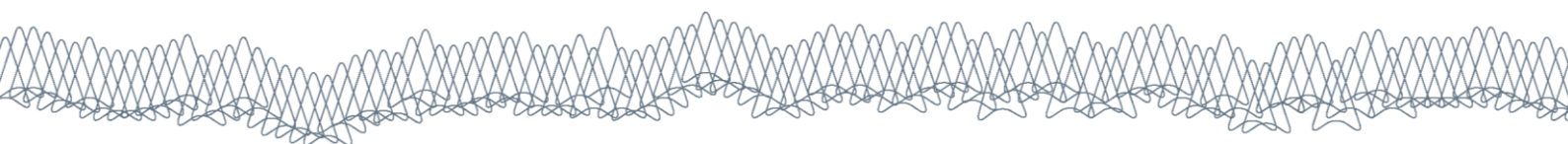


Figure 2.2 Comparison of four analyses techniques to identify important refugia that all overlap the Australian Wet Tropics bioregion. a) the species distribution modelling; b) the compositional turnover modelling, or Generalised Dissimilarity Modelling; c) the Evolutionary refugia: current species- and lineage-level diversity for rainforest-endemic lizards; d) the Zonation conservation planning analysis; and e) the current protected areas within this region.

Source: Adapted from Reside *et al.* (2013).



are known to be important for many species currently in the AWT; however they are likely to miss the areas important for species in other parts of Australia that are likely to move into the AWT as a result of climate change.

The current protected areas (Figure 2.2e) mostly overlap with the important refugial areas predicted by the analyses 2, 3 and 4; however, large areas of refugia predicted by analysis 1 fall outside the current protected areas. The differences resulting from analysis 1 in comparison to the others are almost certainly because this approach focuses on areas that will act as refuges for species that are moving from outside the AWT; namely, from the north and west, and moving uphill from the lowland areas of the western slopes. Additionally, these results do not account for endemism, or for specific habitats (e.g. rainforest endemics).

The southern Atherton Tablelands, which contains the largest tract of upland rainforest, some of the highest diversity and abundance of rainforest species, and high productivity, was well-represented by analysis 4, and by the evolutionary refugia (analysis 3), but under-represented by the two Australia-wide analyses (1 and 2). In contrast, the northern uplands of Windsor and Carbine Uplands gain particularly high refugia status across all techniques (Moritz *et al.* 2005). In the case of Windsor, it is currently moderately depauperate in comparison to other upland areas, with a fauna that is likely to have been recolonised after rainforest contractions in the past. It is also likely to be particularly vulnerable to changes in future rainfall, which is difficult to predict given the uncertainty around rainfall projections.

The southern upland rainforest of the AWT, particularly Hinchinbrook Island, Paluma Range and Mt Elliot, emerge as important refugia across all refugia analyses.

Southern and upland areas of the AWT hold high importance, even if current diversity is low, because the upland areas hold high potential for species currently at lower elevations or lower latitudes to move into. The evolutionary refugia are also concentrated at high elevations in most regions, indicating their importance

as refugia from past climate change. Despite the differences, the congruence across techniques gives us confidence that the techniques used in this study are able to point to high value refugia.

The east coast of Australia had a high proportion of refugia when compared to the rest of Australia.

The Australian east coast is likely to be important by providing an opportunity for species to track their climatic niche south, where temperatures are lower, at the same time finding hydric refugia. While in combination Tasmania and the east coast of mainland Australia will be crucial for species persistence into the future, the refugia found away from the east coast will be crucial for maintaining the unique fauna in habitats other than what is found on the east coast.

The Australian Wet Tropics Bioregion is likely to be an important area for many species moving from the west and north of this region.

The distributions of 1681 species were modelled in an Australia-wide analysis, and their distributions were projected onto future climate change scenarios. More details on the methods can be found in the report by Reside *et al.* (2013). The species were grouped by class: birds, frogs, mammals and reptiles. Areas across Australia were scored for being the most important for both the number of species moving into an area, as well as the number of species that are likely to retain their current occupancy into the future (Figure 2.3). This analysis shows that the east coast is highly likely to be very important for many species in the future, particularly the western edge of the Wet Tropics region.

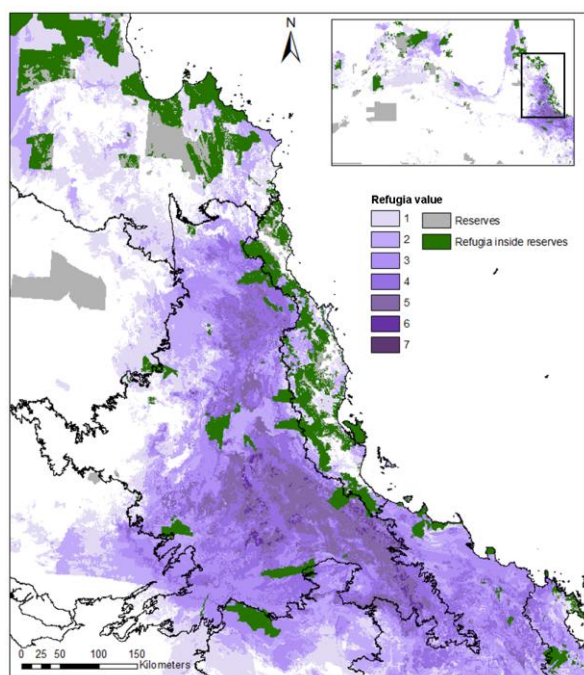
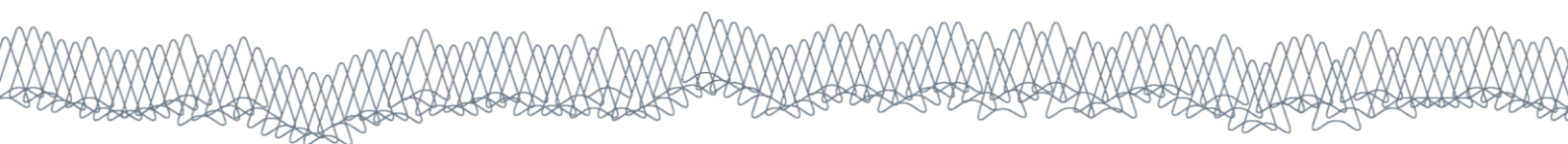


Figure 2.3 A detailed view of the protected areas in Australia's national reserve system, and how they relate to the projected refugia areas in 2085 for north-eastern Australia within the bioregion boundaries outlined in black. The detailed refugia are displayed, using the same scale as the refugia analysis, scaled from 1 (lowest priority) to 7 (highest priority), as the highest possible score '8' was not realised for any location.

Source: Adapted from Reside *et al.* (2013)

Considerations for identifying freshwater refugia

Adaptation for freshwater ecosystems must include the identification, protection and management of current and future refugia, especially in areas predicted to remain climatically relatively stable.

Species may shift in latitude and elevation (James *et al.* 2013), therefore it may be appropriate to consider higher-latitude habitats of the same nature, and all higher elevation habitats, as valuable in the future. Previous modelling work has identified areas in which biodiversity may remain stable or even increase (James *et al.* 2013). Natural adaptive range shifts are least likely to happen the higher the elevation of the habitat,

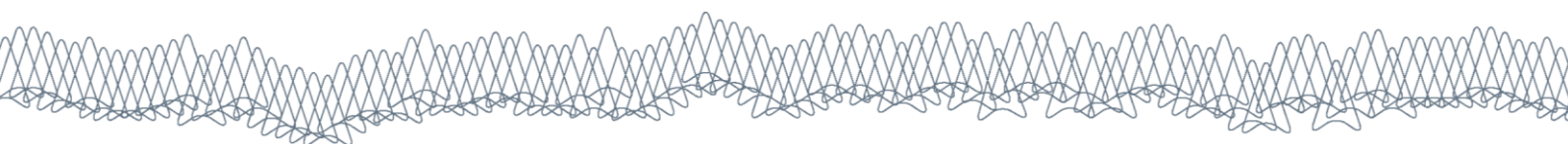
as freshwater habitats become increasingly isolated from each other with increased elevation (Bush *et al.* 2012).

The WTC Region is expected to retain a large proportion of its freshwater biodiversity; therefore has conservation importance at a national level.

For freshwater fish and stream frog assemblages, the WTC Region is expected to remain relatively stable and retain a large proportion of its biodiversity (James *et al.* 2013); this region should therefore be considered especially valuable, at a national level, for freshwater conservation. Fortunately, there is already a strong overlap between the current areas of high value for frogs and the protected area network (James *et al.* 2013); strengthening compliance and education in these areas should be a priority. The WTC Region may also increase in refugial value for species expanding into the WTC Region from other areas (James *et al.* 2013). For crayfish, east coast habitat, which is already at higher elevations, is expected to contract or disappear entirely (James *et al.* 2013).

Identifying refuges specific to freshwater biodiversity will require the consideration of refuge value, including abiotic factors, biotic factors, anthropogenic factors, spatial factors and temporal factors.

James *et al.* (2013) modelled possible range expansions and contractions of Australian freshwater species (Figure 2.4), and discuss the merit of different adaptation options. Much of the scientific climate change adaptation literature has little to offer beyond recommending the protection of potential refuges (Table 2.2). James *et al.* (2013) further distinguish between refuges based on what kind of impact they might be protecting species from, such as warming and heatwaves (e.g. preservation or restoration of riparian vegetation cover, preserving and enhancing groundwater flows by minimising fine sediment input), flow regime changes, floods and droughts (provision of environmental flows and the maintenance of hydraulic habitat complexity), sea level rise and storm surges (maintaining, restoring or enhancing vegetation buffers to storm surges) and fire (protecting networked but unaffected reaches during the recovery phase,



managed relocation of individuals from neighbouring catchments or anthropogenic refuges).

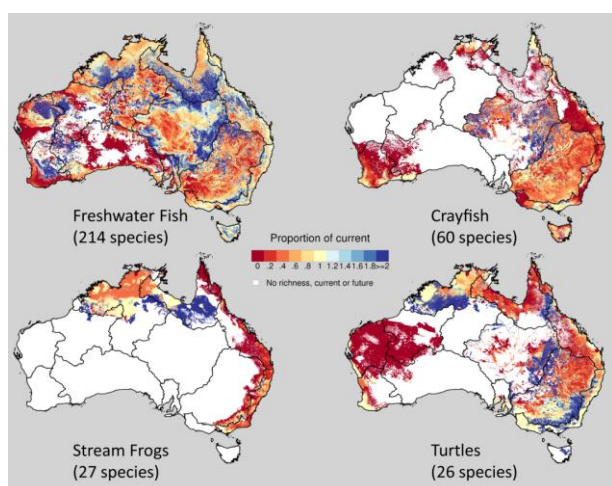
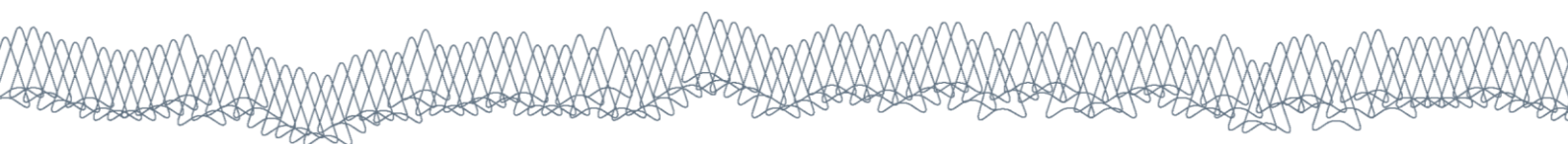


Figure 2.4 Proportionate change in environmental space suitable for freshwater biota between current and 2085 under RCP8.5. Figures represent the 50th percentiles across 18 GCMs. (Blue indicates gains in environments suitable for and red indicates losses in environments suitable)

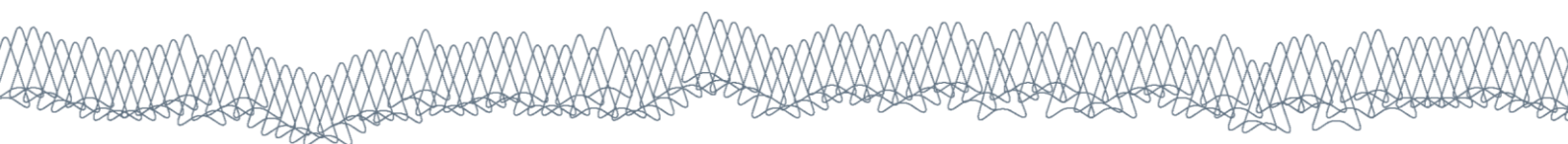
Source: James *et al.* (2013)

Table 2.2 Specific adaptation options associated with the protection and/or enhancement of climate refuges for freshwater biodiversity.

ADAPTATION OPTION	REFERENCE	TYPE OF ACTION	TARGET BIODIVERSITY COMPONENT	RELEVANT SCALE(S)
Management of temperature inverted haloclines	Stith <i>et al.</i> 2011	Manipulation of abiotic factors	Florida manatees, temperature-sensitive species	Ecosystem
Water movement and use of waves to prevent build up of wave intolerant invasives in shallow habitats	Urban and Titus 2010	Manipulation of abiotic factors, Manipulation of biotic factors	Native aquatic plants	Habitat
Retain riparian trees in groups in forestry clearing practices	Chan-MacLeod and Moy 2007	Manipulation of anthropogenic factors, manipulation of spatial factors	Temperate pondbreeding frogs	Ecosystem, landscape
Provision of internal or peripheral islands in flood-prone habitats (e.g. reconstructed marsh) to provide 'lifeboats' for resident populations and 'landfalls' for flood-borne individuals swept downstream	Sexton <i>et al.</i> 2007	Manipulation of abiotic factors, manipulation of spatial factors	Semi-aquatic snakes	Landscape



ADAPTATION OPTION	REFERENCE	TYPE OF ACTION	TARGET BIODIVERSITY COMPONENT	RELEVANT SCALE(S)
Management of water levels (depths and duration) in 'holes'	Kobza <i>et al.</i> 2004	Manipulation of abiotic factors, manipulation of temporal factors	Native fish	Habitat
Creation of artificial refuges: creation of shallow channel for endangered fish where natural habitat destroyed	Winemiller and Anderson 1997	Manipulation of abiotic factors	Endangered fish	Ecosystem
Use of storage weirs to provide permanent water during droughts	Jacobsen and Kleynhans 1993	Manipulation of abiotic factors, Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, landscape
Creation of stepping stone refuges or corridors for movement and dispersal	Robson <i>et al.</i> 2008	Manipulation of spatial factors	Aquatic biota	Landscape
Maintenance of water depth and duration in waterholes, pools etc.	Robson <i>et al.</i> 2008	Manipulation of abiotic factors, manipulation of temporal factors	Aquatic biota	Habitat
Maintenance of some flooding regimes for riparian vegetation, floodplain vegetation, floodplain wetlands, waterbird breeding, fish movement and food web dynamics	Robson <i>et al.</i> 2008	Manipulation of biotic factors, Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, catchment, landscape
Prevention of physical disturbance of dry beds by limiting extraction, construction, off-road vehicle use	Robson <i>et al.</i> 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem
Protection of tributaries in good conditions	Robson <i>et al.</i> 2008	Manipulation of spatial factors	Aquatic biota	Catchment, landscape
Maintenance of physical structure and connectivity to provide refuges from flooding	Robson <i>et al.</i> 2008	Manipulation of abiotic factors	Aquatic biota	Ecosystem, landscape
Prevention of clearing of vegetation and woody debris	Robson <i>et al.</i> 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, landscape
Prevention of draining of pasture wetlands and urbanisation	Robson <i>et al.</i> 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, catchment, landscape
Topping up refuge pools	Robson <i>et al.</i> 2008	Manipulation of abiotic factors	Aquatic biota	Habitat, ecosystem
Piggy-backing flows on flood peaks	Robson <i>et al.</i> 2008	Manipulation of abiotic factors, Manipulation of anthropogenic factors	Aquatic biota	Catchment



ADAPTATION OPTION	REFERENCE	TYPE OF ACTION	TARGET BIODIVERSITY COMPONENT	RELEVANT SCALE(S)
Inundating lake and floodplain soils to replenish egg and seed banks	Robson <i>et al.</i> 2008	Manipulation of abiotic factors	Aquatic biota	Ecosystem
Dam removal	Robson <i>et al.</i> 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, catchment
Removal of drainage systems	Robson <i>et al.</i> 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, catchment, landscape
Revegetation	Robson <i>et al.</i> 2008	Manipulation of biotic factors, Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, catchment, landscape
Replace woody debris	Robson <i>et al.</i> 2008	Manipulation of abiotic factors	Aquatic biota	Ecosystem
Managing and design anthropogenic habitat for use as refuges	Robson <i>et al.</i> 2008	Manipulation of anthropogenic factors	Aquatic biota	Ecosystem, catchment, landscape
Conserve forest remnants	Suga & Tanaka 2013	Manipulation of spatial factors	Macroinvertebrates	Catchment, landscape

Source: From James *et al.* (2013); see source for references

High-quality refuges tend to have relatively stable abiotic characteristics, including high climatic and habitat stability (but high habitat heterogeneity at larger spatial scales), and a level of uniqueness within their surroundings. These abiotic characteristics then ideally support key biotic components such as sufficient

prey, the presence of symbionts and the absence of competitors or predators. Favourable refuges may be compromised by anthropogenic threats that alter landscapes and connectivity patterns; minimising these threats will be a crucial component in the adaptation of freshwater ecosystems to climate change (Figure 2.5).

Prioritising areas for either restoration or protection

Systematic conservation planning is an important tool for prioritising areas (e.g. refugia) for protection and restoration.

The current global network of protected areas alone is inadequate for conservation (Rodrigues *et al.* 2004); therefore, additional protected areas are required as well as managing unprotected areas to maximise biodiversity outcomes will be required to halt biodiversity decline. Prioritising areas for protection against threats (e.g. protected area) or for restoration accounting for species long-term persistence is best achieved through systematic conservation planning (from here on “conservation planning”) (Margules and Pressey 2000; Watson *et al.* 2011).

Biodiversity conservation, ecosystem service retention and carbon sequestration can all be achieved through prioritising areas for protection and restoration; and many studies are looking at ways to attain these simultaneous goals (Nelson *et al.* 2008; Thomas *et al.* 2012). The first priority is to establish and strengthen

mechanisms for protection of existing vegetation of high value. Loss of existing habitat should always be avoided where possible, as re-creation of habitat rarely, if ever, compensates for the biodiversity lost when an area is cleared or intensively modified (Bekessy *et al.* 2010; Suding 2011), particularly for species requiring old-growth habitats (Lindenmayer *et al.* 2012b). Options for protecting existing habitats include national parks, World Heritage Areas, nature refuges, Ramsar wetland sites, incentives for protection on private land and local government zonings.

Considerations for conservation planning for climate change adaptation:

1. Identify species conservation requirements by predicting future distributions under climate change and identifying connectivity requirements for range adjustments.
2. Set specific objectives: qualitative and quantitative.
3. Identify and investigate trade-offs.
4. Incorporate uncertainty.
5. Locate the priority areas for protection and restoration using conservation planning software.

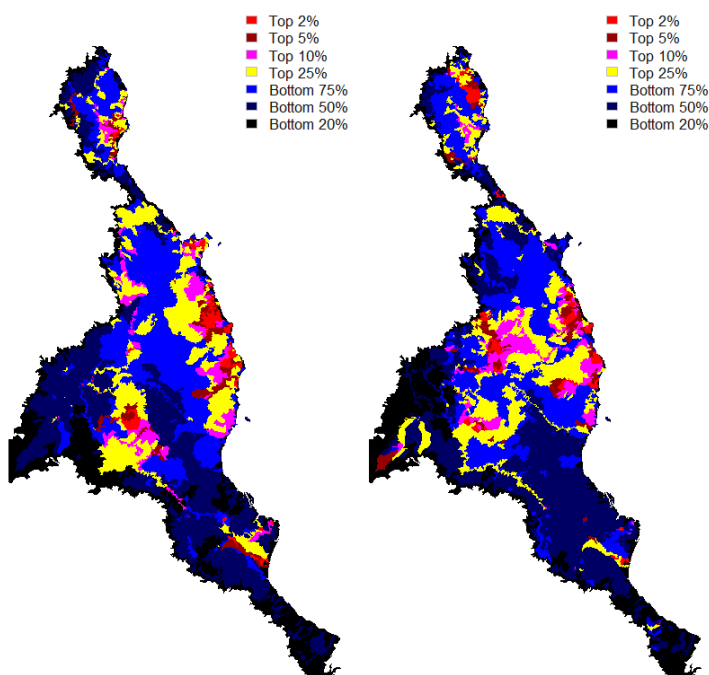
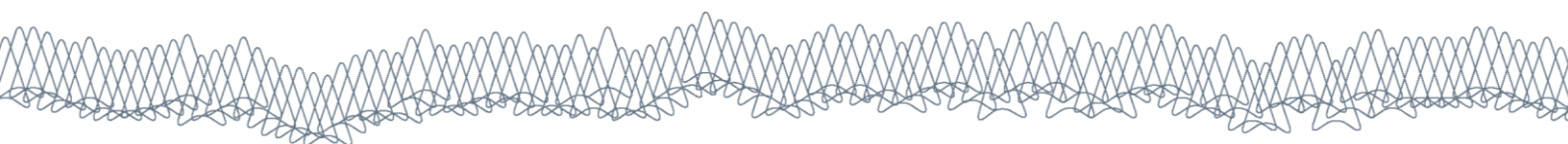


Figure 2.5 Conservation prioritisation of freshwater river catchments within the study area based on 57 fish species for (a) current-modelled species distributions (1990 climate); (b) future-projected species distributions (RCP8.5, 2085, based on the median model across all 18 GCMs). Prioritisation is hierarchical so that the top 2% of cells (red) are within the top 5% (burgundy) which are in turn within the top 10% (pink), 25% (yellow), 50% (blue), 80% (dark blue), the lowest priority 20% are black.

Source: James *et al.* (2013).



Trade-offs occur when one aspect of biodiversity is prioritised at the expense of another; but also when meeting other goals such as carbon sequestration. Trade-offs occur whether they are examined or not, therefore examination of trade-offs supports transparent decision making.

Various conservation planning software tools are available, and their strengths and weaknesses have been reviewed (Moilanen *et al.* 2012). A range of reserve selection algorithms can be used with these software, each weighting different priorities.

Restoration will need to be a major part of climate adaptation.

Restoration is a major part of many climate adaptation action plans, including restoring degraded systems or national parks and increasing connectivity (Gillson *et al.* 2013; Hannah *et al.* 2002b). Restoration has been shown to recover many ecosystem functions and many components of the original biodiversity (Chazdon 2008). Restoration will be required for areas identified as priority for future biodiversity that have become degraded (Shoo *et al.* 2011). Importantly, restoration can facilitate adaptation (restoring areas for species to move to) and mitigation (sequestering carbon) simultaneously, and be economically viable under particular carbon pricing schemes (Bekessy and Wintle 2008). Natural or passive regeneration is the cheapest and often the most effective alternative, but is not always an option (Lamb *et al.* 2005). Conservation planning, monitoring and adaptive management are key to successful restoration projects, regardless of the end goal.

Restoration best practice has evolved to incorporate considerations of climate change adaptation. In particular, focus has shifted away from prioritising local provenance seed and seedlings for planting. Instead, “composite provenancing” is recommended, which involves a mixture of seed from populations of increasing distance to mimic natural gene flow patterns, and increase the chance of bringing in climate change-resilient individuals (see Genetic translocation section) (Breed *et al.* 2013).

The benefits of restoration can often outweigh the costs (De Groot *et al.* 2013). De Groot *et al.* (2013)’s

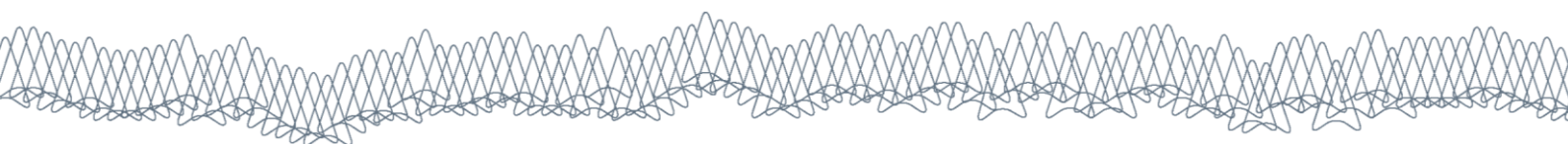
meta-analysis of restoration projects across multiple biomes showed a fairly linearly increasing cost of restoration with increasing distance from the shore: freshwater and inland wetlands had higher costs than terrestrial ecosystems, but lower than coastal wetlands, coastal systems and coral reefs. However, they found that restoration of coral reefs and coastal areas had among the highest natural-capital benefits. Restoring terrestrial systems can be advantageous for increasing both the ecosystem function of the land, and reducing the impact of aquatic systems through reduced runoff, buffering river water temperatures, adding terrestrial carbon for aquatic food webs and providing woody material for fish habitat (Davies 2010).

Translocation as a management tool

Species are likely to face the loss or geographic shift of suitable habitat with climate change (Reside *et al.* 2012; Reside *et al.* 2013). Where species are unable to disperse to new areas with suitable conditions due to lack of dispersal ability, geographic or biological barriers, or insufficient population capacity (Åizling *et al.* 2009; Boulangeat *et al.* 2012), assisted colonisation has been discussed as a potential adaptation option (Harris *et al.* 2013; Hewitt *et al.* 2011; Hoegh-Guldberg *et al.* 2008; Lunt *et al.* 2013). Assisted colonisation has recently been conducted in the Wet Tropics, in regards to the translocation of individuals of a critically endangered frog from the last remaining wild population to a nearby historical site. This frog declined due to disease, not for climate-change associated threats. However, some lessons may be taken from this case study; and further considerations for genetic translocation are discussed below.

General considerations for translocation

Translocation is here considered to be movement of individuals from a wild population directly to another wild site. The important distinction is whether the translocation involves movement of individuals within the known historic range (in which case it can be considered a ‘reintroduction’) or movement of



individuals beyond the known range. The former of these has occurred many times in Australia and internationally, whereas the latter is highly controversial. Here we specifically discuss translocation within the known historic range as a potential management tool.

Any translocation of species is highly risky, with high failure rates, even to a historically occupied site. The factors that determine the success of translocations include: removing threats, number of individuals translocated and the genetic diversity of the founding population. The success of translocations is species and situation-specific and many factors need to be considered.

In September 2013, 40 individuals of the critically endangered Armoured Mist Frog (*Litoria lorica*) were translocated to a new site in an attempt to establish a second wild population. Extensive surveys had shown that there was only one population remaining of this species, on a stream on the western side of the Carbine Tableland (Conrad Hoskin & Robert Puschendorf, unpublished data). Like many Wet Tropics stream frogs, the species declined in the late 1980s and early 1990s due to chytrid fungus disease (Puschendorf *et al.* 2011). The translocation was conducted by Dr Conrad Hoskin (JCU) and the Threatened Species Unit of the Queensland Department of Environment and Heritage Protection. The translocation was to a site upstream, past a barrier of unsuitable habitat, to another extensive area of suitable stream habitat within the historic range. Both sites have been monitored for frogs for many years and are part of a study investigating environmental refuges from chytrid in the Wet Tropics (Puschendorf & Hoskin, unpub. data).

The decision to conduct a translocation in this species took many years and was based on the following criteria for conducting a translocation (Hoskin & Puschendorf, unpublished):

1. Only if the species is known (or very likely) to have been at the site in recent time.

This increases the likelihood that the environment at the new site is suitable for the species, and decreases the likelihood that the translocated species will

detrimentally impact other species at that site (i.e., it will co-occur there with species it has co-occurred with in recent time).

2. Only if the species has been thoroughly surveyed for at this site and elsewhere across the historic range and adjacent areas.

Thorough surveys to determine the existence of overlooked populations are crucial. It needs to be certain that the translocation attempt is really necessary and that the species is definitely absent from the translocation site (to avoid mixing populations).

3. Only if threats are understood and there is a solid reason to believe the species will do well at the new site.

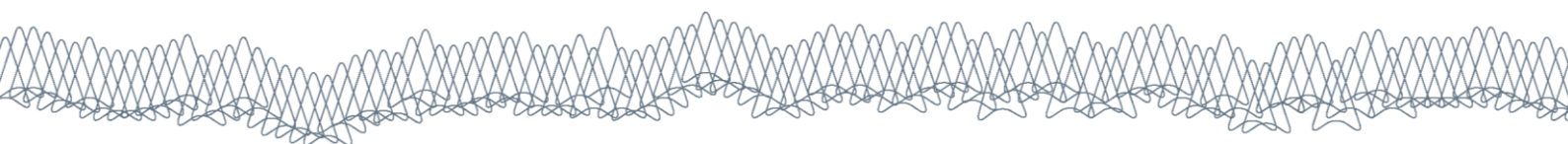
Is the threat absent at the new site? For how long? Or if it is present, can you be sure the species will handle it there?

4. Only if the source population can handle the removal of animals.

Translocations are inherently risky with no guarantee that the translocated animals will survive or establish a viable population; therefore, it is important to be sure that removing them will not be a significant threat to the source population. If the source population is persisting well (which requires extended population monitoring), it may be acceptable to take up to 10%. This is highly dependent on many factors, such as breeding strategy, breeding success, population trends, etc. Population modeling could be incorporated to quantify the risk.

5. If there are multiple populations, then the population genetics must be known to make an informed decision on which source population to use for translocation.

If there are multiple populations, then they are likely to be genetically different and this needs to be investigated. Highly localised species (e.g., single mountain-top endemics or those with a single population) tend to be genetically homogenous due to their small population size and connectivity. In these cases, the options to maximise genetic diversity in the



translocated population include: (i) move as many individuals as is possible without impacting the viability of the source population, (ii) source individuals from different parts of the population, and (iii) maximise the number of individuals contributing to breeding (e.g., consider sex ratios and breeding systems).

These criteria were fulfilled in terms of the *Litoria lorica* translocation (Hoskin & Puschendorf, unpublished):

1. *L. lorica* was almost certainly present at the translocation site 25 years ago, pre chytrid disease outbreak in the Wet Tropics.
2. The northern Wet Tropics region was thoroughly surveyed over several years and *L. lorica* was found to be absent from all likely habitat elsewhere, and years of monitoring other frogs at the translocation site had shown with high certainty that the species was absent there.
3. Years of chytrid research in the region had shown that *L. lorica* and other stream frogs are persisting well despite chytrid infection at the source site (Puschendorf *et al.* 2011). With regards to this threat, the translocation site was deemed highly suitable due to environmental similarity to the source site and high abundance and persistence of the sister species *L. nannotis* there, despite chytrid infection.
4. The main population of *L. lorica* is common throughout the area of suitable habitat and this site is considered 'at capacity'. The population size has been estimated, and monitoring shows no population decline over years. Less than 10% of adults were translocated.
5. Only a single population existed pre-translocation. To maximise genetic diversity, individuals were moved from the middle of the source population, equal number of males and females were moved, and almost all females were gravid when moved.

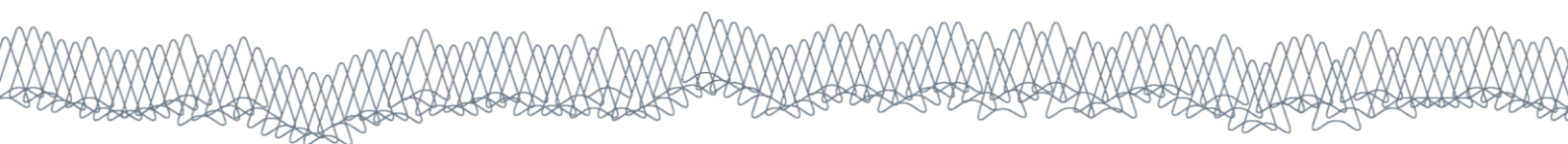
The translocated population of *L. lorica* is regularly monitored and it is too early to determine whether it has been successful. Measures of success will include: survival of the translocated adults, successful breeding and recruitment at the site over the next few years, and, longer-term, population growth at the site.

Meeting all the above criteria will maximise the likelihood of success for the population being translocated, and minimise the impact on the recipient environment. However, it is very rare that all these considerations will be met. The above criteria require thorough research and could only be realistically satisfied in some species. One of the biggest issues in the above list is understanding the threat posed to a species and determining with some certainty how the translocated population will handle that threat at the new site. In the case of the frog example here, the threat is disease and this threat has been studied in detail at all the sites involved. Disease is not a simple threat to study, but other threats, such as climate change, are considerably harder to resolve.

Another big issue in the above list is determining with a high degree of confidence what the impacts on the recipient environment will be. In the case of the reintroduction of a species to a site it was present at in recent history (as for *Litoria lorica*), such impacts can be assumed to be minimal. In the case of translocation of individuals beyond their known historic range, such impacts may be near impossible to determine and predict. Hence such translocations are highly contentious and have not been performed for native species in the Wet Tropics.

Another big issue in the above list is determining how many individuals can be removed from a source population without impacting its long-term viability. This is obviously very complex and will be species and situation-specific. What is the size of the source population? Is it continuous or structured? Is it stable or declining? How rapidly will removed individuals be replaced? From where should individuals be taken? And when? Allied to these questions is consideration of the genetic composition of the source and founding populations. All these are complex questions that can only be answered through detailed study of the specific system in question.

As stated at the outset, the above discussion is based on a case study of a single well-studied frog system. Considerations would be different for a different species of frog, let alone a threatened species of plant or invertebrate. And considerations would be very different when considering translocation as a



management tool for climate change threats. In particular, climate change threats have raised discussion of moving species outside of their known historic range. Our discussion above does not deal with this. Support for this would need to be thoroughly scrutinised. In particular, there is the obvious potential for impacts on recipient environment. Shifting a species outside its range introduces a novel species into an environment, with potentially significant impacts on other species that would be very hard to accurately predict. Beyond this fundamental issue, moving a species outside its known range into a novel environment intuitively reduces the likelihood of establishment success. Translocation outside of the known range is, for good reason, very contentious and widely considered ‘playing god’. It would require considerable debate that we do not enter into in detail here.

Ultimately, any translocation should be seen as a low success, last resort management option that requires detailed system-specific data.

Genetic translocation in the WTC Region

The facilitation of gene flow between populations through assisted interbreeding can be used to enhance the evolutionary potential of populations.

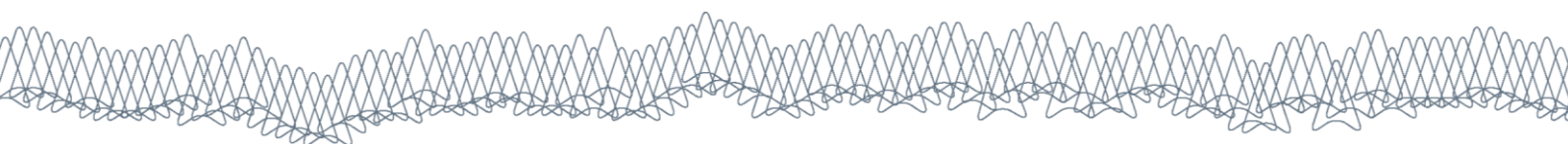
Species may adjust to a changing climate through evolutionary adaptation (Bradshaw and Holzapfel 2006). However, evolutionary responses are dependent on the presence of appropriate adaptive variation; if a population is to rapidly adapt to a different climate, it requires adaptive variation (genes) suited to that climate. Whilst there can be adaptive variation in climate sensitivity within populations, theoretical and empirical studies suggest the bulk of a species’ adaptive variation is found across populations rather than within population (Hampe and Petit 2005). The facilitation of gene flow between populations through assisted interbreeding can, therefore, be used to enhance the evolutionary potential of populations of plants and animals. This emerging conservation tool is known as genetic translocation (Weeks *et al.* 2011).

Isolated populations on the periphery of a species’ distribution may be adapted to the climatic conditions that will develop in core areas of the species’ distribution as climate change proceeds.

Peripheral isolates — small, naturally isolated populations (as opposed to isolated through human-mediated habitat fragmentation) on the periphery of a species’ distribution — are an important source of adaptive variation of climate-relevant traits. These populations are likely to be particularly diverse in terms of climate adaptation because: (1) their location at the periphery of the species’ distribution means they are likely to be exposed to extreme climatic conditions (relative to the species’ tolerance), and (2) their isolation decreases or prevents gene flow from neighbouring populations and allows for local adaptation to the conditions encountered in the isolate (Aitken *et al.* 2008). Peripheral isolates on the hot periphery of a species’ distribution may, therefore, be adapted to hot conditions, i.e., they may be adapted to the climatic conditions that will develop in core areas of the species’ distribution as climate change proceeds. Thus, hot-adapted peripheral isolates could hold the adaptive variation needed by core populations if core populations are to evolutionarily adapt to warmer conditions. As climate change proceeds, however, conditions will also become hotter in hot-adapted peripheral isolates at a much faster rate than in the past. Given the small size and isolation of these isolates, and given that they are already at the limit of the species’ thermal tolerance, hot-adapted peripheral isolates are particularly vulnerable to climate change. Thus, as temperatures become even hotter, hot-adapted peripheral isolates may be some of the first populations to disappear. Thus, the application of genetic translocation in building resilience to climate change requires urgent attention.

Facilitating gene flow between lineages and/or from peripheral isolates to core populations could bolster the evolutionary potential of populations in the WTC Region.

Research in the WTC Region suggests genetic translocation could be used to improve climate change resilience of species from this region. The WTC Region



consists of a complex network of rainforest patches, with large central patches of rainforest that experience relatively cool to mild climate, as well as smaller peripheral rainforest isolates that are exposed to more extreme conditions. Populations of rainforest specialists that have been able to persist in the small isolated patches of rainforest are likely to be adapted to the conditions encountered in the isolates; they may hold adaptive variation in thermal and desiccation tolerances that is not present in core populations. Furthermore, many WTC Region endemics display a complex phylogeography (geographic distribution of genetic groups), consisting of multiple lineages that are isolated from one another. In some cases, these lineages are known to be divergent in their climate sensitivity (Moritz *et al.* 2012). Thus, facilitating gene flow between lineages or from peripheral isolates to core populations could bolster the evolutionary potential of populations in this region. Genetic translocation is, however, a controversial and relatively costly conservation strategy (Shoo *et al.* 2013). Even so, it is a strategy that is increasingly being considered (Weeks *et al.* 2011), and appears particularly well-suited to the WTC Region given the structured phylogeography and local adaptation seen in species endemic to this region. Before genetic translocation can be safely and effectively used in this region, further research into its application is required. More specifically, genetic translocation protocols need to be developed to ensure that if/when this strategy is used it: (1) improves the resilience of recipient populations, and (2) threats associated with the transfer of organisms between habitat patches are minimised.

Triggers and thresholds

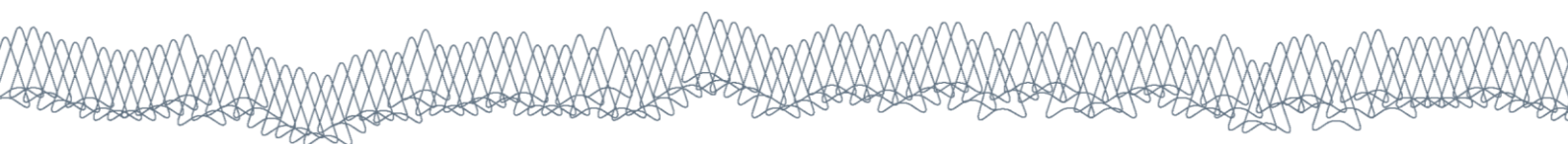
The uncertainty inherent in climate change predictions makes it almost impossible to determine set triggers or thresholds beyond which ecosystems are likely to change irrevocably.

Management of complex ecosystems depends on being able to measure the responses of organisms to the main drivers of change (Bino *et al.* 2014). The most useful information for managers to understand and act upon often take the form of indicators, thresholds and

triggers (Eiswerth and Haney 2001; Werners *et al.* 2013). Threshold responses can be measured and quantified, identifying potential transitions between ecosystems states, with the inclusion of uncertainty in the form of the time range in which tipping points are likely to be reached (Werners *et al.* 2013).

Understanding minimum thresholds transitioning from desired to undesired states can help manage the system for resilience (Groffman *et al.* 2006). However, thresholds can rarely be generalised across large spatial and temporal scales (de Boer 2007). Additionally, the uncertainty inherent in climate change predictions makes it almost impossible to determine set triggers or thresholds beyond which ecosystems are likely to change irrevocably. In the coral reef literature, for instance, there is much discussion of “phase shifts” from a desirable stable state (coral-dominated) to a less desirable stable state (e.g. algae-dominated), with very little prospect of a reversal (Graham *et al.* 2013). But even in this case, it has not been possible to define set thresholds in environmental parameters (e.g. temperature, nutrients, turbidity, herbivore biomass) that will trigger a phase shift, or even how long it takes a system, once the threshold has been crossed, to reach a new stable state (Graham *et al.* 2013). For instance, the bleaching threshold for Great Barrier Reef corals varies between species and across spatial scales, and is dependent on a complex set of variables including both the duration and magnitude of thermal stress (Spillman *et al.* 2013).

In the context of assessing the suitability of refugia for supporting future changes in species ranges and community structure, understanding thresholds is equally difficult. Managing the whole landscape, rather than refugia on their own, may provide a better safeguard where refugia do not perform as predicted under climate change. Understanding the resilience of refugia will depend on our ability to ascertain what the limits are of that resilience. For instance, there may be rainfall levels below which a refugium is no longer able to sustain species that migrate into it (Keppel and Wardell-Johnson 2012). Predicting the value of refugia based on thresholds is especially complicated in the case of species that are nomadic (Bino *et al.* 2014).



Previous studies that have identified environmental thresholds have highlighted that these are often specific to a particular location or time.

Bino *et al.* (2014) modelled fluctuations in 10 species of colonial waterbird species in the Macquarie Marshes of NSW over 24 years (1986-2010), and found that all species had different thresholds in water flows that triggered breeding events. Waterbird species included great egret (*Ardea alba*), intermediate egret (*A. intermedia*), little egret (*Egretta garzetta*), cattle egret (*Bubulcus rufous*), night heron (*Nycticorax caledonicus*), glossy ibis (*Plegadis falcinellus*), Australian white ibis (*Threskiornis mollucca*), straw-necked ibis (*T. spinicollis*), little pied cormorant (*Microcarbo melanoleucos*), and little black cormorant (*Phalacrocorax sulcirostris*). All these species also occur in some parts of the WTC Region, but may respond to different water flow thresholds in different parts of their range. Hilbert *et al.* (2014) used the known successful incubation temperature of turtles (25-34°C) to predict that nesting beaches in the northern Great Barrier Reef and Torres Strait region will produce a higher proportion of females by 2030 and will experience incubation temperature that constantly exceed the upper thermal incubating threshold by 2100.

Among the 10 Australian ecosystems considered most vulnerable to tipping points, seven occur in the WTC Region.

Among the 10 Australian ecosystems considered most vulnerable to tipping points, seven occur in the WTC Region (Table 2.3): elevationally restricted mountain ecosystems, tropical savannas, coastal floodplains and wetlands, coral reefs, drier rainforests, offshore islands, and salt marshes and mangroves (Laurance *et al.* 2011). Whilst specific tipping points are not identified or predicted, the authors recommend a number of actions to prevent tipping points. To determine whether a tipping point may be approaching, key ecological processes and ecosystem dynamics must be identified and examined. Disruptions to ecological processes and slowing of ecosystem dynamics may both point to impending shifts, as can increases in spatial variance and autocorrelation measured by remote sensing (Laurance *et al.* 2011). The authors also advocate for local management actions to reduce the risk of tipping points, such as increasing the protected area networks, limiting external disturbances such as habitat destruction for urban and road development, creating corridors and buffers, restoring habitat and managing fire regimes (Laurance *et al.* 2011).

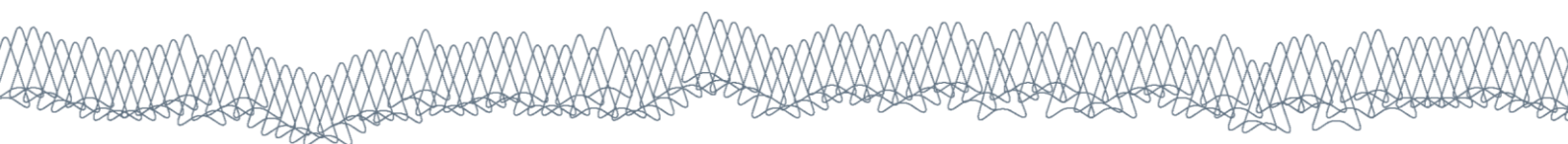
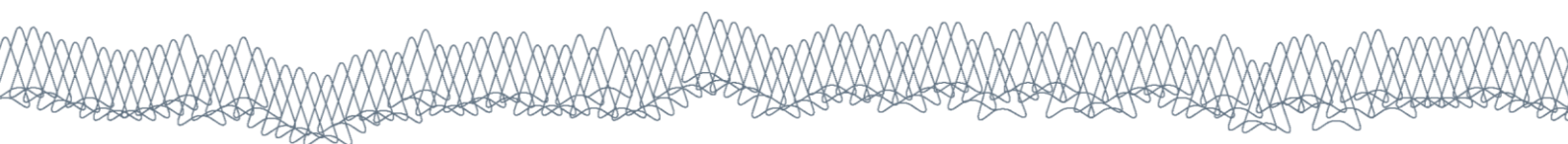


Table 2.3 Intrinsic features and environmental threats that render the 10 most vulnerable Australian ecosystems prone to tipping points. For each ecosystem type, the most important feature is numbered 1 with those of lesser importance numbered subsequently.

	Mountains	Tropical savannas	Coastal wetlands	Coral reefs	Drier rainforests	Islands	Estuarine wetlands
Narrow environmental envelope	1		4	1	1	2	1
Near threshold	3			3			
Geographically restricted	2		1		2	1	2
History of fragmentation			2		3		4
Reliance on ecosystem engineers		3					
Reliance on framework species				2			6
Reliance on predators or keystone mutualists							
Positive feedback		1		4	4		
Proximity to humans			3	5	5		3
Social vulnerability		2					5
Increased temperatures	1			1	2	6	
Changes in water balance and hydrology	2		3		3		3
Extreme weather events	3	3	2	2		2	1
Ocean acidification				3			
Sea-level rise			1			3	2
Changed fire regimes	8	2	8		1		
Habitat reduction	5		5	5	5	4	4
Habitat fragmentation	6	4	6	6	6	5	
Invasives	4	1	4		4	1	
Pests and pathogens	7					7	
Salinisation				4			
Pollution			7				5
Overexploitation		5		7	7		

Source: Laurance *et al.* (2011)



Fire management

Fire offers a number of opportunities for adaptation management, including prescribed burning of weedy flammable species and woody species encroaching on native grasslands. However, timing of burns will be critical to success in terms of biodiversity management.

In general, fire offers more opportunities for adaptation management and intervention than other aspects of climate change (Low 2011). Prescribed burning at key times to manage fuel accumulation, particularly of invasive flammable grasses including gamba grass (*Andropogon gayanus*) and buffel grass (*Cenchrus ciliaris*), will become an important management strategy under climate change in order to decrease the potential for extensive wildfire and protect habitat for wildlife. However, climate change is expected to shift fire season length in the region, and shorten the time suitable for prescribed burns. There may also be complex effects on fuel loads - on the one hand, elevated CO₂ may enhance vegetation production and increase fuel loads, but on the other, drought may decrease long-term vegetation production (thereby decreasing fuel loads) and may decrease fuel moisture (thereby increasing potential rates of spread) (Williams *et al.* 2009).

Prescribed burns may also be critical in controlling the spread of woody plants into grasslands in the region (Witt *et al.* 2009). Woody thickening is a considerable problem in the region and has been observed most consistently in northern Australia. However, there is the potential for perverse outcomes associated with altered burning regimes which focus on reducing emissions, for example, in Far North Queensland, invasion of grasslands by paperbark is related to repeated early dry season burns and subsequent overgrazing (Witt *et al.* 2009). This highlights the current lack of integrated fire management regimes in the region.

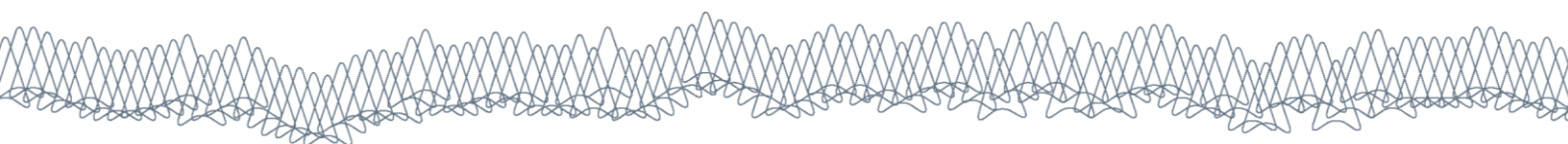
For some terrestrial species, an increase in woody vegetation may provide more habitat, but other species rely on an open habitat and shade intolerant plants and native grasses could be threatened or outcompeted by encroaching shrubs and trees. Some species are directly

threatened by woody thickening - the endangered golden shouldered parrot, endemic to Cape York Peninsula, is impacted through increased predation risk and impacts of thickening on seasonal food availability (Crowley *et al.* 2004). Prescribed burning is considered the best method to stall thickening, although the timing of the burn is vitally important - in the north, late dry season burns and storm-season burning favour the maintenance of grassland, while burns at other times favour the encroaching tree-line.

Fire management strategies will need to be adapted for different habitats and woodland types, and take into account faunal species within communities and previous seasons for fire management.

While there is great potential to use fire as an adaptation tool to manage some of the impacts of climate change on biodiversity, caution should be taken and the capability of different species and ecosystems to withstand fire must be considered in different regions. For example, while some plant species are well adapted to fire, others can be vulnerable to frequent fire events. Surveys following repeat fires suggest that most rainforest plants can survive high fire frequency and vegetatively resprout following fire (Williams *et al.* 2006b). However, some rainforest and sclerophyll plants are killed by high frequency fire, such as the rare, restricted shrub *Banksia plagiocarpa* (Williams *et al.* 2005b). Furthermore, burns too early in the season may not maintain an open structure, while very hot fires may kill seeds outright, especially of fire-sensitive species. For other species, fire could stimulate germination rates, though this can be detrimental when the interval between fires is too short and the regenerated plants are burnt before they fruit and restore the soil seed bank. Timing of burn has also been shown to influence native fauna, with wet season and dry season burns in the tropics favouring different assemblages in the time following the burn (Valentine *et al.* 2007).

In summary, the impacts of climate change on fire regimes in the WTC Region are complex and so developing adaptation management strategies to reduce risk to biodiversity and maintain ecological integrity will be challenging. Management decisions



should reflect the fact that fire regimes will be influenced by other factors, such as exotic species and land-use change, which may affect fuel loads. Appropriate management actions for biodiversity will differ among regions, but may include regimes that aim specifically to manage fuel accumulation and flammable invasive grasses, such as prescribed burning, or planting fire retardant vegetation. The life history and other attributes of focal species should be taken into account, and diverse fire regimes should be applied to encourage habitat and species diversity.

Connectivity for movement and migration

Coastal and marine communities

Climate change is driving a southward migration of tropical marine communities (Beger *et al.* 2014) and, where undeveloped space is available, a landward migration of coastal communities such as mangroves and dunes (Saintilan *et al.* 2014). Some communities may replace others; for instance, mangroves have been replacing salt marshes, especially at their poleward limits (Saintilan *et al.* 2014). Traditionally, marine conservation planning has addressed climate change or connectivity, but not both (Magris *et al.* 2014).

Adaptation efforts will need to be geared towards maintaining connectivity for assemblages to expand into new areas; impact minimisation or mitigation will need to target not just existing communities, but areas to the south (for tropical marine communities) and west (coastal communities).

Mangroves, with their pioneer-species characteristics, have the ability to rapidly colonise new areas as these

areas become suitable (Alongi 2008; Soares 2009); barriers to this movement will be the dense and rising coastal development taking place along the WTC Region coastline (Eslami-Andargoli *et al.* 2013). Similarly, coastal wetlands can adapt by maintaining their elevation relative to sea level, given the opportunity for the maintenance of sediment deposition rates and, where possible, active management of water flows (Rogers *et al.* 2014; Saintilan and Rogers 2013). Helping these coastal ecosystems to persist (and therefore migrate) will require the availability of space into which they can migrate (Gilman *et al.* 2008; Soares 2009) - recently termed “managed retreat” (Saintilan and Rogers 2013) - and adequate migration corridors (Williams *et al.* 2005a). This will require integration between climate change adaptation management and urban planning, and may result in “more compact urban forms that may lead to reductions in the cost of defence against sea level rise, reduce energy usage per person and provide more green space” (Burley *et al.* 2012).

Modelling can predict where, when and how severe coastal erosion and sea level rise might be (Nicholls and Tol 2006). Rehabilitation of coastal communities in areas that have become eroded due to sea level rise and increasingly intense tidal and storm surges is becoming more urgent, but can be expensive, and is not always a priority. Bell and Lovelock (2013) propose a scheme in which the coastal protection function provided by mangroves could be insured, and provide recommendations to policy-makers and the insurance industry. Given the similar function performed by most types of coastal vegetation, this concept could easily be extended to maintain or rehabilitate all coastal community types. Whilst “hard” adaptation options were most common in the past, “soft” options are increasingly considered (Hallegatte 2009) (Table 2.4).

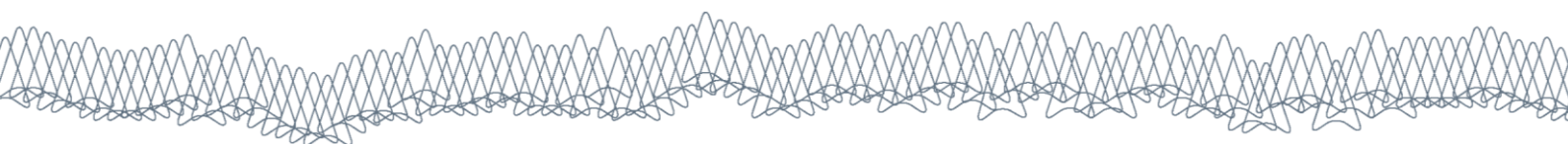
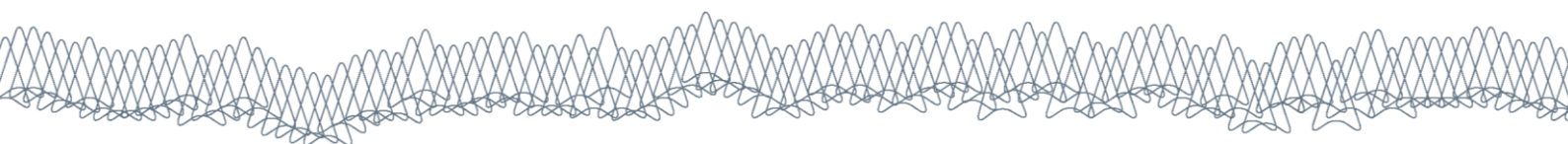


Table 2.4 Hard and soft adaptation options highlighted by Burley et al. (2012), modified with information from Gilman et al. (2008)

		HARD	SOFT
Anticipatory	Planning stage		
	High resolution mapping of lands and the distribution of land use		Have risk-appropriate insurance policies
	Select locations for wetland migration inland to increase the probability of maintaining wetlands of sufficient size and diversity to achieve the objectives (maintenance of ecosystem services and biodiversity)		Have planning regulations to restrict the use of land in high-risk area for infrastructure, encouraging alternative uses (wetlands)
	Increase the density of the urban footprint (increase room for wetlands and decreasing costs associated with defence)		Have an institutionalised long-term planning horizon to anticipate responses & awareness of climate change effects on wetland distribution
			Planning regulations specifying optimal land use and greenhouse gas capture, that is, the amount of wetlands to be maintained, the amount of catchment sediment and nutrient loads
			Develop regional and town plans that take into account a changing climate
	Design and construction stage		
	Design landscapes to accommodate landward wetland migration		Financial incentives for the development of 'soft' engineering options for coastal protection
	Limit defence against sea level rise to high value infrastructure.		Financial incentives for retreat from high-risk property in order to increase size and connectivity of wetlands
	Redesign roads and other structures to accommodate wetland connectivity		Incentive payments for increased carbon sequestration
	Use 'soft' engineering approaches to sea level rise (beach or wetland nourishment)		
	Change land-use patterns in new developments to accommodate coastal wetlands at appropriate elevations relative to sea level (Andrey and Mills 2004)		
	Manage rate and location of groundwater extraction		
	Operating and maintenance stage		
	Weed and feral animal control		Financial incentives for better maintenance and operating practices
	Monitoring and management		Establish legal limits for tolerance of weeds, ferals, mosquito
	Improve access for the community (tracks, boardwalks, bird-hides, fishing)		Market-based incentives (increased housing prices with access to green space)



		HARD	SOFT
Reactive	Maintenance and operating stage		
		Nourish wetlands, mangroves and saltmarshes with sediment to allow wetland accretion to keep pace with sea level rise	Increase protection of vulnerable and endangered species (e.g. strengthen fisheries penalties, enforce protected area compliance). Eliminate non-climate stresses to augment overall ecosystem health
		Create artificial environments for the maintenance of species populations (e.g. production of juveniles, sturgeon)	Increase regulation of pollution (increase standards)
		Increase waste water treatment capacity	Emergency management plans, evacuation and climate advisories to reduce risk during storms
		Build walls, groynes, revetments, bulkheads for protection from storm surges and erosion	Incentives for mitigation projects
		Rehabilitation, reforestation	Creation of information databases regarding climate impacts & effectiveness of adaptation strategies—learning by doing approach
		Production of flooding intensity maps for flooding relief	Monitoring programs and education of the public

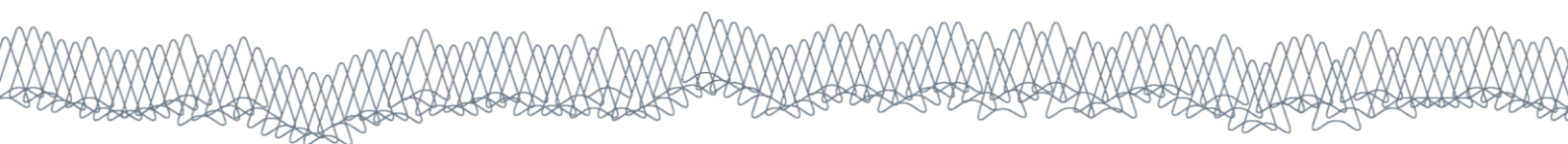
Terrestrial biodiversity and landscape connectivity

Increasing landscape connectivity is important for addressing conservation issues resulting from habitat fragmentation, and also for enabling shifts in species' distributions in response to climate change.

Large areas of good quality habitat are the cornerstone of biological conservation and will be critical to the ability of species to adapt to consequences of climate change (Hodgson *et al.* 2011; Hodgson *et al.* 2009; Travis 2003). However, climate change will alter the distribution and extent of suitable climate space for Australian terrestrial animals (Reside *et al.* 2013) and plants (Hilbert and Fletcher 2012). Thus, connectivity between areas that lose and those that gain suitable climate space will be necessary to facilitate species' biogeographical range shifts. In the WTC Region for example, easterly shifts in suitable climate space into the Mackay-Whitsunday-Isaac and Wet Tropics areas are predicted for a large number of species from western parts of the region (Reside *et al.* 2013).

Connectivity is a landscape property that emerges from the interaction between attributes of the landscape and of plant and animal species. Connectivity relates to the amount, quality and spatial arrangement of habitat in a landscape and how this either enables or presents barriers to the movement of plants and animals. There has been a shift in emphasis from physical connectivity (i.e., structural features that are perceived by humans as being connected) to functional connectivity (i.e., whether or not a given species can actually move through a given landscape), where even habitats that appear to be physically unconnected may be functionally connected or conversely where habitats that appear to be physically connected may be functionally unconnected.

Habitat clearing and fragmentation have created barriers to movement for most taxa, and biodiversity conservation strategies typically include increased landscape connectivity as an important objective. Adaptation of terrestrial biodiversity to climate change will also require strategies that surmount barriers to movement, although the spatial scales involved are likely to be large and the time frame short.



Increasing connectivity has an important limitation as a strategy for adaptation to climate change in that suitable climate space is projected to disappear from the region for a range of species, such as endemic upland taxa in the Wet Tropics bioregion (Williams *et al.* 2003) and species dependent on coastal freshwater aquifers. Increasing landscape connectivity will contribute neither to the ability of these species to persist nor their adaptive capacity under climate change. While translocation to geographically distant areas with suitable climate space could potentially avoid species' extinction, it would likely only ever be an option for a small subset of species, would not preserve ecosystems, and may have negative impacts in recipient systems.

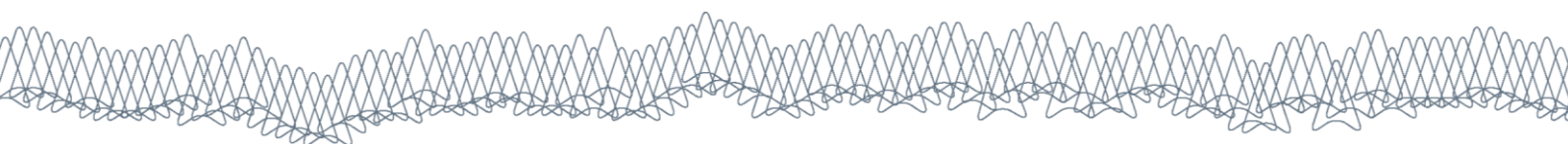
The amount of good quality habitat in a landscape is positively related to degree of connectivity. Linear features may also be important, especially at smaller spatial scales.

The degree of connectivity of a landscape is closely related to the amount and distribution of good quality habitat available (Hodgson *et al.* 2011; Hodgson *et al.* 2009). Simply increasing the amount of habitat in a landscape can increase connectivity for some species. For example, Doerr *et al.* (2013) modelled a range of plausible future landscapes for parts of northern New South Wales and determined that, in respect to connectivity, "Even random placement of new areas of native vegetation achieved similar outcomes for biodiversity on average as principles based on careful spatial planning". However, the importance of spatial arrangement of habitat increases dramatically as the level of landscape habitat cover decreases, so that where habitat cover falls below 30%, the spatial arrangement of any additional habitat has a strong effect on its contribution to connectivity. In a well-vegetated landscape, any addition of habitat is more likely to be near to (and functionally connected with) other habitat areas.

While strategies for improving connectivity now include generally increasing levels of good quality habitat cover in the landscape, continuous linear features may be important for increasing connectivity for some organisms, especially those that cannot traverse

cleared and modified land. Continuous strips of vegetation are most typically located along watercourses, and these areas are commonly targeted for protection and restoration as movement corridors. Riparian areas are thought to be used for navigation through the landscape by mobile species such as flying foxes, are known to support high numbers of species and to provide critical habitat for a range of flora and fauna, especially in lower rainfall regions. Riparian areas also provide refuge during hot days, which are predicted to become more frequent throughout the Wet Tropics cluster. Furthermore, protection and restoration of riparian areas have potential co-benefits for the conservation of aquatic systems and water quality improvement. Importantly, fringing riparian vegetation can often be maintained or restored without the loss of substantial areas of productive land and so represents a relatively palatable option for land managers. However, because adjacent floodplain areas are highly productive, riparian vegetation is typically narrow, surrounded by cultivation or grazing. While riparian strips provide habitat for a large range of animals and plants, it has been suggested that corridors that are at least 300-500 m wide are needed to promote connectivity at regional scales (DECC NSW 2007). This would likely require legislative support given current patterns of land use. Importantly, riparian corridor networks will not improve connectivity for flora and fauna that are associated with non-riparian ecosystems, nor will they facilitate movement between riparian and non-riparian habitats. In order to understand the trade-offs of focussing conservation actions in riparian areas it would be useful to identify the species associated with riparian and non-riparian habitats, accounting for seasonal movements, together with their ability to move through cleared and modified landscapes.

The contribution of linear connectivity features to surmounting barriers to movement is easier to conceive at smaller spatial scales. For example, movement of rainforest arboreal mammals is deterred by breaks in forest canopies caused by transport, energy and water supply infrastructure (Goosem 2004). Rope bridges can transcend this barrier effect across small (ca. 15 m) gaps, although the effectiveness of these structures across larger gaps is uncertain (Goosem 2004). Road



underpasses can improve connectivity, especially where they incorporate surrounding habitat restoration and elements of habitat structure (e.g., logs, rocks) (Goosem 2004). Other actions that improve connectivity across transport infrastructure include the use of roadside reflectors (e.g., successful in reducing roadkill in Proserpine rock wallaby *Petrogale persephone*; Johnson *et al.* 1993), elevated bridges that maintain canopy continuity, and swinging powerlines well above intact canopies. Although many of these measures can be expensive, improving functional connectivity across transport infrastructure is likely to strongly influence the adaptive potential of many species.

Many current projects are based on increasing connectivity at different spatial scales

Species' adaptation to climatic changes will in some cases require very large-scale distributional shifts along broad ecological gradients. This has prompted continental-scale connectivity initiatives such as the Great Eastern Ranges ('Alps to Atherton') project which aims to improve connectivity among habitats along the Great Dividing Range between southern Victoria and the Atherton Tablelands (Mackey *et al.* 2010). Challenges include identifying critical barriers to movement from present to predicted areas of suitable habitat, as well as facilitating such large geographical shifts over short time scales.

In the Terrain NRM region, the Wet Tropics Management Authority (WTMA) has implemented a "Making connections" project centred around high elevation rainforest areas of Atherton Tablelands, which are considered to be areas of potential refuge from climate change for cool upland endemic species, many of which have limited ability to move across cleared areas. The WTMA is in the process of updating their Connectivity Strategy, prioritising areas on the basis of protecting conservation values of the Wet Tropics World Heritage Area (WHA) specifically. Other areas of the landscape will be important for connectivity in current and future climates and across NRM regional boundaries.

Cleared and modified parts of the landscape may contribute to functional connectivity.

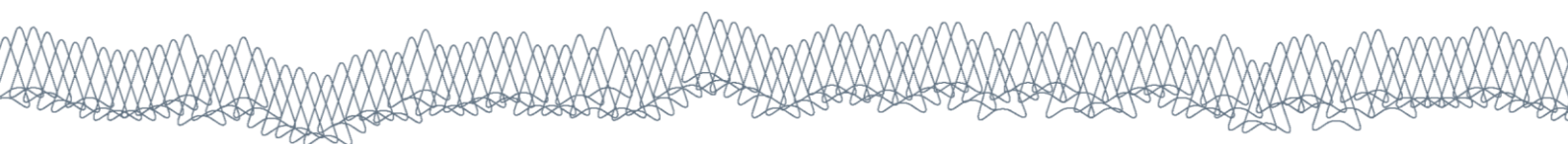
The functional connectivity or "permeability" of landscapes differs among species due to variation in dispersal and life history characteristics. A barrier to one organism may enhance connectivity for another (Manning *et al.* 2010).

It is understood that cleared and modified parts of the landscape (which would not necessarily be considered as habitat) may contribute to functional connectivity. For example, regrowth, including areas dominated by introduced weed species (e.g. *Cinnamomum camphora* camphor laurel) potentially contributes to functional connectivity for both animals and plants (i.e., regeneration opportunities) (Kanowski *et al.* 2003).

Urban and agricultural development can be major obstacles to landscape connectivity for many organisms. In the WTC region, urbanisation is concentrated in lowland coastal areas, especially in the Terrain and Reef Catchments NRM regions. Adaptation to climate change by certain plants and animals in coastal areas will be prevented by a lack of functional connectivity to westward areas (refer to previous section). This is likely to be especially significant for coastline species that will increasingly experience impacts of sea level rise and seawater inundation in the short term. Suggestions for improving connectivity in urbanised areas are typically based around parkland, open areas and street trees (e.g. Manning *et al.* 2010), although other strategies are being tested, such as 'green rooftops' (Braaker *et al.* in press).

One of the risks of increasing connectivity is assisting dispersal of problem species or disease.

One of the risks of increasing connectivity for target species is that it may inadvertently increase connectivity for problem taxa, fire and disease (see also Invasives section). For example, Doerr *et al.* (2013) report an increase in the spread of an introduced species (peppercorn *Schinus molle*) in model landscapes that included planting intended to improve connectivity. However, it is generally considered that the benefits of increasing connectivity outweigh the risks, especially in the context of climate change.



Connectivity can be improved by integrated farm management that includes protection of remnant habitat isolated trees and areas of regrowth, managing dams and modifying fence design.

There is a multitude of examples of integrated farm management actions that increase the connectivity of farmed landscapes for native plants and animals. Increasing habitat area is a primary strategy, achieved by protecting patches of remnant habitat, isolated trees, dams and areas of regrowth vegetation. Removing or reducing barriers to the movement of organisms across properties may also improve connectivity. This may include actions such as reducing the height of fences to allow passage by animals such as kangaroos, and replacing barbed wire with plain to avoid snagging bats and gliders.

Restoration, including biodiverse carbon plantings, may be able to increase connectivity in the landscape.

It is critical that restoration plantings do not replace existing habitat because plantings are likely to take many decades to attain habitat values similar to that of mature systems. Plantations *per se* will not necessarily increase habitat relative to pasture or agricultural land, especially if they comprise few species or low structural diversity. In contrast, biodiverse plantings have the potential to increase the amount of habitat available, even to species with fairly specialised habitat affiliations (Kanowski *et al.* 2005; Kanowski *et al.* 2003), and thus has the potential to increase overall landscape connectivity for these organisms (See restoration section).

Invasive species

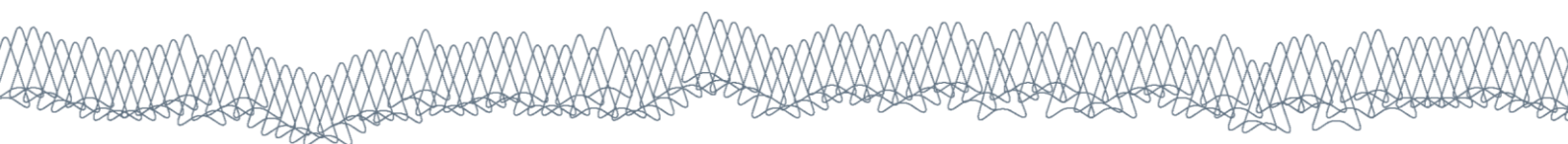
The WTC Region is likely to remain suitable for many weeds and some, such as rubber vine, are predicted to increase under climate change (Hilbert *et al.* 2014). Climate change will also create new opportunities for invasive species to recruit, spread and increase in abundance, particularly following disturbance from extreme events such as cyclones and extreme rainfall (Hilbert *et al.* 2014). Invasive grasses, including gamba grass and mission grass in the monsoonal zone, and buffel grass (*Pennisetum ciliare*) in sub-humid areas are

also likely to increase fuel load and foster larger, hotter fires (Fensham 2012; Hilbert *et al.* 2014).

Existing invasive species threats should be controlled in order to increase the capacity of native biodiversity to adapt to climate change, and adaptation responses to climate change should not create new, or exacerbate existing, invasive species problems.

Developing suitable adaptation actions to control invasive species under a changing climate will require planning at the species, local and regional levels. For example, weed control and habitat restoration should be ongoing actions in priority areas of the WTC Region, including areas identified as climate refugia for native biodiversity. This is because these areas are also likely to be exploited by invasive species (Low 2011), and could potentially allow pest species to persist then disperse when conditions improve. Efforts to create conservation corridors to help native species adapt to climate change may similarly promote the spread and dispersal of invasives unless they are effectively managed in these locations (Hellmann *et al.* 2008) (see also Refugia and Connectivity sections).

The Invasive Species Council (2011) advises that research and control efforts should be directed toward species predicted to exert the highest threats to biodiversity under climate change, such as *Phytophthora cinnamomi* and the flammable invasive pasture grasses. In general, invasive species management under predicted climate scenarios will require a more adaptive and strategic response, and will need to be supported by flexible investment strategies which enable timely responses at critical periods – for example following extreme events (Reardon-Smith *et al.* 2012). Tightening of quarantine and biosecurity measures, and education of landowners about introduced species and their impacts should also continue to be priority adaptation measures. Managers and land-owners should be urged to make use of weed risk-assessment tools freely available, such as <http://weedfutures.net>, which is a decision support tool enabling land managers to make informed decisions about the management of naturalised, but not yet invasive plants at a regional level (Hughes *et al.* 2013).



Reardon-Smith *et al.* (2012) outline a number of priorities to consider when considering climate change adaptation measures for invasive species, including:

- *Early Intervention* – under rapidly changing conditions, control efforts for invasive species are most likely to be successful when implemented at an early stage in the invasion process (Park 2004).
- *Utilise predictive modelling tools*, such as Bayesian Belief Systems – under uncertain outcomes, models can be used to ‘test’ the outcomes of alternative management approaches prior to their implementation (Liedloff and Smith 2010), thereby facilitating cost-effective on-ground invasive species management.
- *Seasonal climate forecasting* – climate forecasting models which can incorporate both invasion and climate change biology with seasonal ENSO forecasts could allow the prediction of outcomes of different management actions, and provide an analysis of the level of risk (or uncertainty) associated with these in different years/seasons. This could provide the capability to adapt invasive species management to changing environmental conditions (Hellmann *et al.* 2008).

Managing reproductive capacity in vegetation communities

Adaptation management actions will require a holistic approach, with the most cost-effective actions occurring for species in-situ. Ex-situ actions, for the most threatened species, may include seedbanking, genetic supplementation or assisted colonisation/dispersal.

The impacts of climate change on the reproductive success of most WTC Region plants is not well known, but growing season, flowering, germination and seeding success are likely to be affected (Low 2011). Obligate seeders, such as the restricted *Banksia*

plagiocarpa from the Cardwell area will likely be particularly at risk (Williams *et al.* 2005).

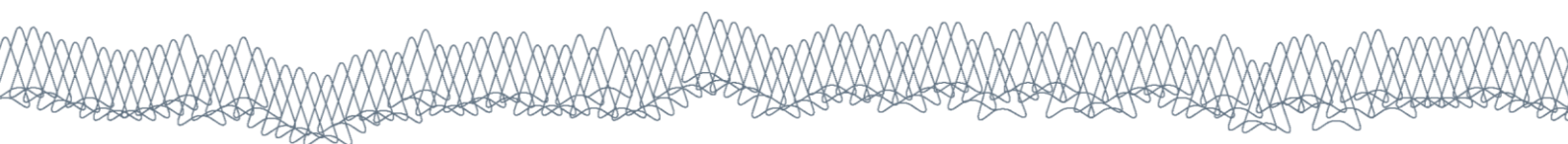
Like other groups of species, adaptation management to maintain reproductive integrity in plant communities will require a holistic and fluid approach. The most cost effective actions will be in-situ, although ex-situ actions may be required for the most threatened species (Table 2.5).

Table 2.5 Potential adaptation management strategies for plant reproduction

POTENTIAL ADAPTATION ACTIONS	
Immediate Actions	<ul style="list-style-type: none"> • Control and eradication of introduced weed and grazing species • Halt to land disturbance and loss, maintaining canopy cover and favourable microclimates • Managing risks of adverse fire regimes • Land management and purchase • Water management • Baseline species and community studies of ecology and adaptive capacity • Risk-assessments of potentially at-risk species
Ongoing Actions	<ul style="list-style-type: none"> • Seedbanking • Assisted genetic flow in isolated populations • Assisted migration/dispersal • Species management
Future Actions	Assisted migration/dispersal

The risks and benefits of adaptations should be taken into account, particularly with actions such as assisted gene flow. Seed-based risk assessment could be an option for some species from the WTC Region.

Actions such as seedbanking, assisted migration and assisted genetic flow should, on the whole, be less expensive than comparable actions in faunal groups. Risks and benefits should be assessed, for example using the risk-assessment framework provided in Weeks *et al.* (2011). Aitken & Whitlock (2013) further



stress that in order to weigh the risks of assisted genetic flow against those associated with maladaptation from climate change, it is imperative to know the species' extent of local adaptation to climate and other environmental factors, as well as pattern of gene flow. Thus baseline surveys and research into the ecology and genetics of key species will be priority ongoing actions. Cochrane *et al.* (2011) developed a seed-based risk assessment approach for Western Australian species under climate change, which could be adapted as a management tool to assess potentially at risk species in the region. They used a two-way temperature gradient plate to profile the germination of more than 45 species across fluctuating and constant temperatures ranging from 5°C to 40°C. Species which germinated within a narrow temperature niche were predicted to be susceptible to climate warming.

Fire could be used as a management tool to promote seed germination in species adapted to a fire-prone landscape and with a 'sprouting' life-history strategy, but timing and frequency of burning should be considered on a case-by-case basis.

Fire could potentially be used as a management tool to promote seed germination in some species and communities adapted to fire, which employ a 'sprouting' strategy following fire. However fire intervals are critical – in a study in the eucalypt forests between Townsville and Cardwell fire was found to promote seed germination and species richness, but intervals of more than eight years were required to allow for the maturation of shrubs (Williams *et al.* 2006b). However, there is the risk that longer fire intervals may lead to woody thickening in some areas – fire interval should be considered on a case-by-case basis.

Finally, when plant reproduction shifts in season, or failures occur, there are associated risks to nectivorous, frugivorous and granivorous fauna, and potentially a feedback effect on seed dispersal (Van der Putten *et al.* 2010). Management actions could include ensuring a diversity of species to ensure different flowering times and pollen supply, and landscape connectivity to ensure access to flowering or fruiting plants (Murphy *et al.* 2012). More specific targeted interventions to restore

disrupted species interactions, including plant-pollinator or plant-herbivore relations, may also be required (Dawson *et al.* 2011).

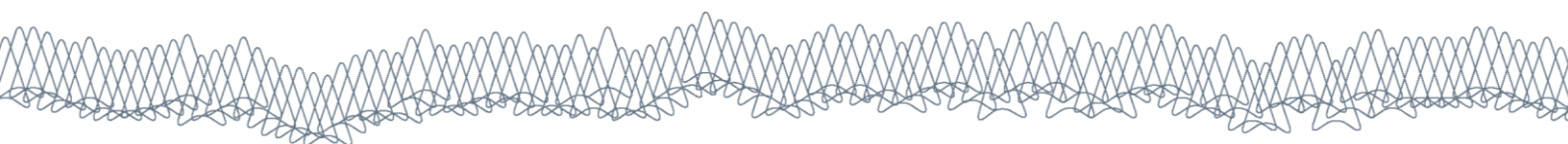
Adaptation for important species and communities

Whilst broader climate change impacts need to be managed at national and global scales, it is widely recognised that assisting species and ecosystem in their adaptation to a changing climate needs to include strategies to enhance their persistence at local and regional scales. Therefore, management of local stressors is seen as equally valuable, especially because the results of such actions tend to be much more readily measurable, and tend to yield results over shorter timeframes (Ghedini *et al.* 2013). Priority species and communities for the WTC region include marine turtles, dugongs and coral reefs. This region also has the highest diversity of birds and flying foxes in Australia, so these are also covered in some detail.

Turtles

Adaptation options for marine turtles are mainly consistent with a reduction in other more immediate impacts.

Marine turtles are expected to be affected by different aspects of climate change depending on the stage in their life cycle. Nesting beaches are affected by rising sea levels and resulting erosion, and changes in temperature. Coastal feeding grounds such as seagrass beds and coral reefs are affected by rising SSTs and changing run-off and turbidity patterns from the land (larger and more frequent floods, storm events). Migration pathways may also be affected by changes in ocean temperature and circulation. While these changes are difficult to control, adaptation can be encouraged by reducing other, more immediate anthropogenic impacts: destruction of nesting habitat and predation of nests, disorientation of hatchlings by artificial lighting, degradation of nearshore marine habitats (especially seagrass beds and coral reefs), declining water quality, boat strike, incidental catch by commercial fisheries and traditional harvesting.



Protecting nesting beaches is the most cost-effective strategy of increasing turtle populations.

Protecting nesting beaches is the most cost-effective method of achieving increases in leatherback populations (Gjertsen *et al.* 2014); this is likely to be the case for other turtle species. Protection of turtles at the nesting stage can include banning beach access to vehicles, general beach closure, the enclosing or direct protection of nests (e.g. with mesh), controlling turtle egg predators (Whytlaw *et al.* 2013), or even surface treatment with habanero pepper powder to deter predators (Lamarre-DeJesus and Griffin 2013). Where beaches are being eroded by sea-level rise or changes in sand deposition patterns from coastal development, other adaptation options may be necessary, such as hard engineering structures or soft measures (see below; Fuentes *et al.* 2010b). Identifying nesting beaches that will either remain or become suitable for turtles in the future will determine where nesting site conservation efforts could be directed in the coming years. Such assessments and predictions could include temperature shifts (as hatchling production may decline for turtle nests in lower latitudes with rising temperatures (Pike 2014; Read *et al.* 2012)) and exposure to changing weather patterns and storm activity. The Relative Exposure Index, which characterises nesting beaches based on the degree of exposure to wind and waves, may be a useful tool in determining which beaches, beyond the ones already commonly used by nesting turtles, would provide suitable nesting sites. A recent analysis showed that turtles tend to nest on high exposure beaches along the mainland Queensland coast (Garcon *et al.* 2010). Some models predict that current turtle nesting beaches along the Queensland coast will be less affected by cyclones, possibly due to past natural selection pressure to nest on beaches less likely to suffer cyclonic conditions (Fuentes and Abbs 2010). Assessments of future range shifts in nesting beaches should take into account predictions of changes in cyclone activity (Fuentes *et al.* 2011); the restructuring of beaches during cyclones may be beneficial to hatching success on beaches with high nest density by removing accumulated nesting debris (Dewald and Pike 2014; Honarvar *et al.* 2011).

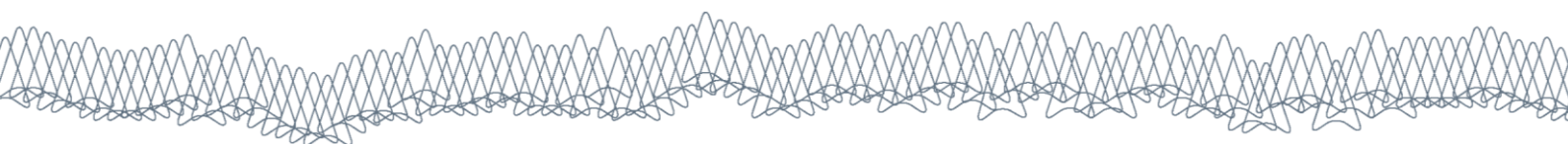
A number of options exist to safeguard the most important nesting beaches from beach loss and inundation, effectively providing a buffer zone. Adaptation options will need to be tailored to individual beaches and the particular threats they face.

A number of options exist to safeguard the most important nesting beaches from beach loss and inundation, including the construction of sea walls or groynes, beach nourishment, dune building, nest shading or setback regulations that prohibit construction within a set distance from the beach, effectively providing a buffer zone (Fish *et al.* 2008; Nicholls and Tol 2006; Wood *et al.* 2014). Moving nests, for instance away from light sources, high-use areas or areas of inundation and erosion, is also possible, and may be increasingly important in the future to safeguard endangered turtle populations (Pfaller *et al.* 2008). However, it is labour-intensive and requires relocation within two hours of oviposition to ensure maximum survival of moved egg clutches (Berry *et al.* 2013).

High sand temperatures can dramatically reduce hatchling success by increasing mortality of embryos (Wood *et al.* 2014). Furthermore, the sex ratio of embryonic marine turtles is determined by nest temperature (cooler nests tend to produce males, and warmer nests females), and climate change is likely to affect these ratios. Chronically biased sex ratios can eventually lead to population collapse (Pike 2014). Hatchling success is also affected by coastal development, especially in areas with bright lighting at night. Various solutions exist for this, including changes to the timing of lighting, the use of low-pressure sodium-vapour lights (which have proven less disruptive to at least loggerheads), reducing the number of lights, building light-barriers, and educating nearby residents (Berry *et al.* 2013).

Maintaining connectivity to suitable nesting habitat near existing nesting beaches, especially inland, will make a considerable difference to the capacity for nesting turtles to adapt to sea level rise.

Modelling studies exist that have explored different sea level rise scenarios in relation to known turtle nesting



beaches (Daniels *et al.* 1993; Fish *et al.* 2005; Fuentes *et al.* 2010b; Katselidis *et al.* 2014). Katselidis *et al.* (2014) identified areas of beach currently used by turtles, the area anticipated to become inundated under each of three sea level rise scenarios, the area anticipated to become unsuitable for nesting under each scenario, the potential for habitat loss under each scenario, and the extent to which the beaches were likely to shift in relation to natural (i.e. cliffs) and artificial (i.e. beach front development) physical barriers. Similarly to other studies, they found considerable nesting habitat loss (31-48%) even under the most conservative scenario, but losses were much more pronounced when there were barriers. Maintaining connectivity to suitable nesting habitat near existing nesting beaches, especially inland, will make a considerable difference to the capacity for nesting turtles to adapt to sea level rise. In Australia, a similar study on islands of the far northern GBR concluded that up to 38% of green turtle rookeries could be inundated (Fuentes *et al.* 2010b).

The identification and protection of feeding grounds will also provide an important buffer to changing climate conditions.

Turtles in the coastal waters of the WTC Region feed primarily on seagrass beds and coral reefs. Both are under increasing pressure from a number of human impacts. Locating, protecting and enhancing turtle feeding habitats can ensure that adult turtles in coastal waters are able to persist. Seagrass and coral reef adaptation options are described in the following sections (Dugongs and Coral reefs).

Reductions in direct mortality from boat strike, fisheries by-catch, plastic debris and disease must be controlled, and stranded turtle rehabilitation need to continue.

Reductions in fisheries by-catch have already take place in Australian coastal fisheries, mainly through the implementation of turtle excluder devices (or TEDs)(Brewer *et al.* 2006). Identifying the intersections between foraging habitat and migration pathways and commercial fisheries can further help managers target these areas for conservation actions (Griffin *et al.* 2013). Ghost nets also continue to cause significant

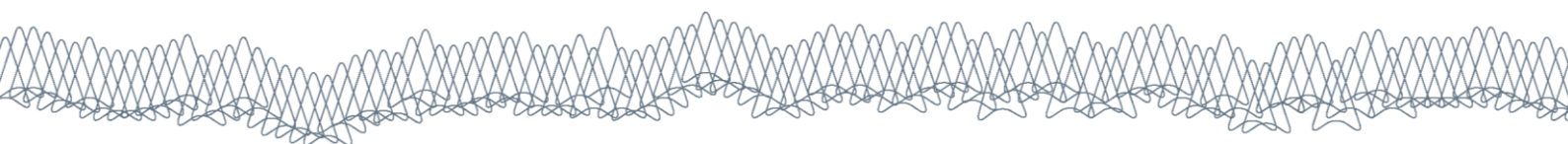
mortality in turtle populations in the Torres Strait and off Cape York; ongoing research seeks to understand and mitigate this impact (Wilcox *et al.* 2012). In areas where traditional sea turtle hunting continues, it is crucial that modern and traditional styles of management be interwoven to find a balance between resource management and conservation (Butler *et al.* 2012). Ongoing active rehabilitation of stranded and injured turtles should continue, especially the quest to discover the causes and sources of disease (Flint *et al.* 2010) and the reduction of plastic debris available for ingestion (Schuyler *et al.* 2013).

Dugongs

Protecting dugong feeding habitat and reducing direct anthropogenic mortality should be the priorities of any adaptation program.

The primary issues facing dugong populations are incidental catch, subsistence use, habitat destruction, and impacts of oceanic pollution (Gillespie 2005). On the GBR, the threats that most urgently require management are commercial netting and indigenous hunting, and vessel traffic, terrestrial runoff and commercial netting in more urbanised areas (Grech and Marsh 2008). Seagrass beds, the primary food source of dugongs, are being lost globally and in Australian coastal waters (Waycott *et al.* 2009).

As with marine turtles, protecting dugong habitat should be one of the priorities of any adaptation program with climate change in mind. The re-zoning of the Great Barrier Reef Marine Park in 2004 included the consideration of dugong habitat, but fell short of protecting 50% of high priority dugong habitat as recommended in the design guidelines (Dobbs *et al.* 2008). Consideration should be given to the fact that high priority dugong habitat identified then may have disappeared or moved; mapping current habitats and tracking their future movement will indicate where changes in protection might be required. Predictive modelling has been used to map known and likely seagrass habitats (Grech and Coles 2010), this could be expanded to indicate the likely future extent of seagrass beds. Seagrass is highly responsive to water quality (Grech *et al.* 2011), potentially exacerbating periodic



seagrass dieback and adversely affecting reproduction and survival of dugongs (Marsh and Kwan 2008). Water quality must be improved if the inshore areas of the GBRMP are to provide suitable habitat for resilient ecological communities into the future (see also Coral reef section). Some water quality thresholds from the inshore GBR include:

- Mean daily irradiance $> 5 \text{ mol m}^{-2} \text{ d}^{-1}$ was associated with gains in seagrass; 16–18% of days below $3 \text{ mol m}^{-2} \text{ d}^{-1}$ was associated with more than 50% seagrass loss (Collier *et al.* 2012).
- Four hours of light saturated irradiance was associated with increases in seagrass abundance, and less than 4 hours of light saturated irradiance with more than 50% loss (Collier *et al.* 2012).

Dugong mortality can be minimised through fishing closures, gear modification and boating restrictions.

Minimising direct mortality should also continue to be a priority, including fishing closures, gear modification (Hodgson *et al.* 2008), and boating restrictions. Commercial netting has been one of the most significant sources of dugong mortality on the GBR, but the rezoning of the GBRMP significantly reduced this threat (Grech *et al.* 2008). Gear modification of coastal fisheries with TEDs and by-catch reduction devices have further reduced direct mortality (Brewer *et al.* 2006). Minimising boat strike mortality must include speed or even access restriction of boats in critical dugong habitat, coupled with better knowledge of dugong movements (Whiting 2008). The management of traditional dugong hunting is a complex cultural, social, economic and environmental issue that continues to receive considerable attention (Kwan *et al.* 2006).

Coral reefs

Creating protected areas achieves rehabilitation of coral reef systems.

On coral reefs, local management actions are often focused on the reduction of immediate human pressures (Graham *et al.* 2013), such as by creating protected areas or reserves, with the hope that these

will support the recovery of intact food webs, and therefore support the resilience of the community to the more global effects of climate change (Hughes *et al.* 2010; McClanahan *et al.* 2011; Pandolfi *et al.* 2011). This has proven to be successful in places where fisheries target a wide variety of prey including herbivores; once herbivores are protected, they reduce algal biomass and support the dominance of corals. On the GBR, herbivores are not targeted by fisheries; no-take areas generally result in the recovery of large piscivores such as coral trout and sharks. The most important factor in ensuring that marine reserves adequately protect the ecosystems within them is ensuring compliance (Pollnac *et al.* 2010). Building adaptive capacity to climate change into the design of marine reserve networks will require careful planning around size, shape, representation, connectivity and ecosystem-based management (Table 2.6) (McLeod *et al.* 2009).

In addition to recommendations following McLeod *et al.* (2009), a recent study outlines a framework to incorporate both climate change and connectivity into conservation planning (Magris *et al.* 2014). The following set of complementary approaches is described which relate to marine reserves:

1. stating preferences for spatial configuration of marine reserves and their placement relative to critical areas in the seascape
2. applying generic 'rules of thumb' for size and spacing of marine reserves
3. tailoring replication and representation objectives to the requirements of specific conservation features
4. using ecological insights to guide rules for spatial relationships among features in decision support tools
5. defining objectives for structural or functional surrogates
6. predicting and targeting functional surrogates based on analysis of dynamics (Magris *et al.* 2014).

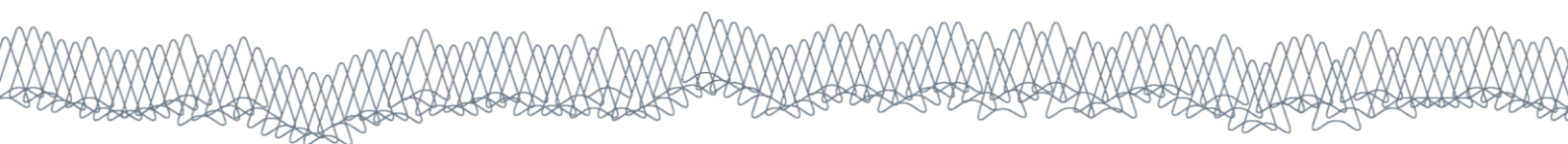


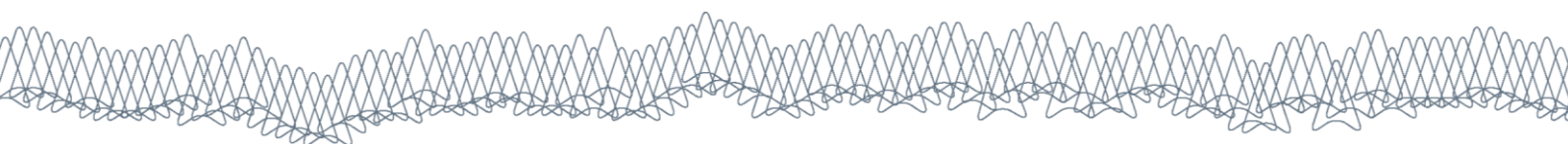
Table 2.6 Recommendations for marine reserve design to maximise adaptation to climate change.

CATEGORY	RECOMMENDATIONS
Size	Bigger is better - MPAs should be a minimum of 10-20 km in diameter to be large enough to protect the full range of marine habitat types and the ecological processes on which they depend, and to accommodate self-seeding by short distance dispersers.
Shape	Simple shapes should be used, such as squares or rectangles, rather than elongated or convoluted ones, to minimise edge effects while maximising interior protected area.
Risk spreading (representation, replication and spread)	Representation: protect at least 20-30% of each habitat type. Replication: protect at least three examples of each marine habitat type. Spread: ensure that replicates are spread out to reduce the chances they will all be affected by the same disturbance event. Select MPAs in a variety of temperature regimes using historical sea-surface temperatures and climate projections to ameliorate the risk of reefs in certain areas succumbing to thermal stress caused by climate change.
Critical areas	Protect critical areas that are biologically or ecologically important, such as nursery grounds, spawning aggregations, and areas of high species diversity. Protect critical areas that are most likely to survive the threat of climate change (e.g. areas that are naturally more resilient to coral bleaching). These may include areas cooled by local upwelling, areas shaded by high, steep-sided islands or suspended sediments and organic material in the water column, reef flats where corals are adapted to stress, and areas with large herbivore populations that graze back algae and maintain suitable substrates for coral larvae to settle on.
Connectivity	Take biological patterns of connectivity into account to ensure MPA networks are mutually replenishing, to facilitate recovery after disturbance. MPAs should be spaced a maximum distance of 15-20 km apart to allow for replenishment via larval dispersal. Accommodate adult movement of mobile species by including whole ecological units (e.g. offshore reef systems) and a buffer around the core area of interest. Where this is not possible (e.g. coastal fringing reefs), protect larger versus smaller areas. Take connectivity among habitat types into account by protecting adjacent areas of coral reefs, seagrass beds, and mangroves. Model future connectivity patterns to identify potential new coral reef substrates, so that measures can be taken to protect these areas now, and accommodate expansion of coral distribution to higher latitudes.
Maintain ecosystem function	Maintain healthy populations of key functional groups, particularly herbivorous fishes that feed on algae, facilitating coral recruitment and preventing coral-algal phase shifts following disturbances.
Ecosystem-based management	Embed MPAs in broader management frameworks that address other threats external to their boundaries (e.g. integrated coastal zone management or an ecosystem approach to fishing). Address sources of pollution (especially enrichment of water), which create conditions that favour algal growth and prevent coral larvae from settling. Monitor changes in precipitation caused by climate change that may increase runoff and smother reefs and seagrass beds with sediment

Source: McLeod *et al.* (2009).

The benefits of restoring coral reefs currently outweigh the costs, except at very localised scales, but opportunities for improving restoration options should be considered, as this may be increasingly necessary in the future.

While marine reserves continue to be the most common marine conservation tool, some scientists call for a wider range of approaches, including unconventional options (Table 2.7) (Rau *et al.* 2012). More direct local actions may involve active restoration through the transplantation of corals (especially more heat-tolerant species, populations or symbiont clades)



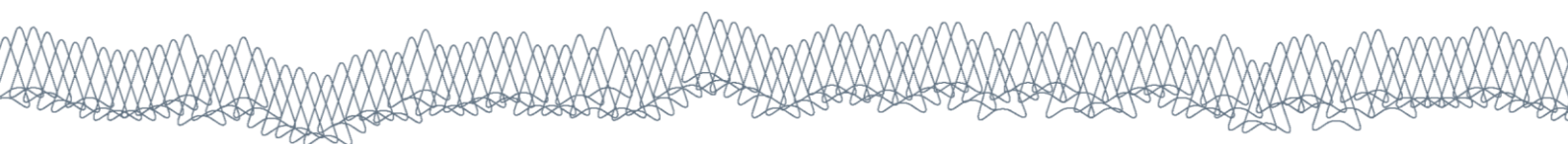
to heavily degraded sites. In the context of climate change, active coral reef restoration remains hotly debated (Bellard *et al.* 2012; Briggs 2009). Generally, active restoration has been possible only at very small scales, and only with a limited range of coral species (Omori 2011). Only recently has coral “gardening” been advocated and trialled on a larger scale (Rinkevich 2008); in a recent study 10,000 planulae of the brooding coral *Stylophora pistillata* were reared to 5-month-old colonies - essentially genotypes of equal size to small branch fragments - requiring 676 person-hours (Linden and Rinkevich 2011). Critics argue that the cost outweighs the benefits due to the uncertainty of

survival and establishment of transplanted populations at a new location, and the effects of relocated species on local populations may be detrimental. However, in some cases relocation (or “assisted colonisation”) may be the only way for keystone species to overcome dispersal or migration barriers (Hoegh-Guldberg *et al.* 2008). The actual goal of restoration (enhancing coral cover or diversity, maintenance of heterogeneity, or recovery or endangered species) should drive the choice of species used (Muko and Iwasa 2011), and frameworks are being developed to manage the decision process and costings of relocation for climate change (Richardson *et al.* 2009).

Table 2.7 Examples of conventional and unconventional conservation methods, and their potential to address the global stressors of temperature, CO₂ acidity, and excess atmospheric CO₂. X denotes direct effect; (X) indicates possible indirect effect; ? indicates uncertain.

CONSERVATION METHOD	STRESSOR ADDRESSED			CONSERVATION METHOD	STRESSOR ADDRESSED		
Conventional:	Temp	Acid	CO ₂	Unconventional:	Temp	Acid	CO ₂
Marine reserves and coastal zone management	?	?	?	Physical — for example, sun shading, solar-radiation management; increased upwelling	X		(X)
Pollution and watershed management	?	?	?	Biological — for example, selective breeding, artificial selection, genetic engineering; creation of refuges; artificial preservation of genetic stock	X	X	(X)
Fisheries, shipping and recreation management	?	?	?	Chemical — for example, chemical, electrochemical or geochemical modification of seawater (alkalinity addition, pH elevation)	(X)	X	X
Carbon dioxide emissions reduction — increase energy efficiency and non-fossil fuel energy use; decarbonise fossil energy	X	X	X	Hybrid and other approaches — for example, conversion of waste carbon dioxide to ocean alkalinity; storage of land crop waste in ocean; ocean fertilisation	(X)	X	X

Source: Rau *et al.* (2012)



Rehabilitation may also consist of recreating underlying structural complexity where this has been destroyed (e.g. dredging, trawling, storms), giving settling coral larvae a chance to become established. Timing of restoration activities is likely to be crucial, and should coincide with relatively stable climatic periods (e.g. outside the cyclone / flood season) and periods of coral recruitment and episodic macroalgal die-off (Graham *et al.* 2013). Reef restoration has not been widely applied in Australia, but a risk assessment framework exists for minimising uncertainty (Hoegh-Guldberg *et al.* 2008). Translocation of corals to higher latitudes, which are the most likely refugia for tropical coral reefs in warming seas, has not yet been attempted (Beger *et al.* 2014). Difficulties arise based on the symbiosis between corals, their zooxanthellae and other microorganisms; within this complex relationship, the thermal tolerance of all components must be taken into account (Fine *et al.* 2013; Ortiz *et al.* 2014; Weis 2010).

Structural complexity is the most important restoration focus for coral reef communities.

Any active restoration efforts should consider that coral reef communities depend on the coral for structural complexity more than anything else. Some fish eat live coral, and many others recruit into live coral (Graham *et al.* 2013; Pratchett and Berumen 2008), but much of the community depends on structural complexity over and above live coral cover. Once the coral dies, it can take years for the structure to erode to the point where the community shifts to an alternate stable state (Graham *et al.* 2013). This means that if the early stages of a shift are detected, the likelihood of a reversal is much higher (Graham *et al.* 2013). Steps that can be taken to halt or reverse a phase shift include timely management of fisheries to enhance large fishes, bolstering processes such as herbivory, and ensuring that habitat structure is not further eroded.

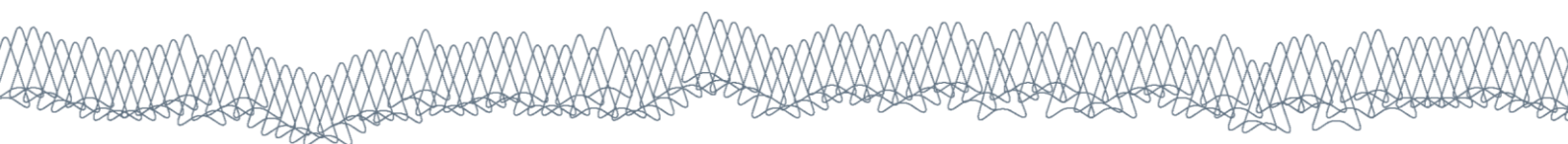
Identifying future refugia for coral reef organisms, or even whole coral reef communities, will be a crucial factor in assisting coral reef adaptation to climate change.

Coral reef organisms are likely to expand southward along the Queensland coast, as those closer to the

equator reach the limits to their thermal tolerance, and southern waters warm to the point of providing favourable temperatures (Beger *et al.* 2014). Identifying future refugia for coral reef organisms, or even whole coral reef communities, will be a crucial factor in assisting coral reef adaptation to climate change. To this end, protection of subtropical reefs and future suitable reef habitat needs to be strengthened (Beger *et al.* 2014). Identifying source reefs and connectivity pathways (Beger *et al.* 2010), and enhancing connectivity between source reefs and future potential refugia will also become increasingly important; there will be a need to prioritise areas of lower environmental stress, relative climatic stability and high social and economic adaptability (Cinner *et al.* 2011). Modelling occurrences of high sea surface temperature anomalies on the GBR has already taken place (Ban *et al.* 2012), as well as the association between climate stress and coral reef diversity in the western Indian Ocean (McClanahan *et al.* 2011); extending this modelling to identify areas to the south likely to maintain temperatures that are relatively stable could be the next step.

Inshore reefs of the GBR are urgently in need of improved water quality management, both at the catchment scale and locally (e.g. around ports).

Currently, inshore reefs are in a state of decline because a naturally low density of large herbivores, high sedimentation rates and the artificial input of nutrients are enhancing the growth of macroalgae, and in recent years higher temperatures have prevented the seasonal macroalgal die-off. Additionally, it is thought that elevated nutrients enhance the survival of larvae of the corallivorous crown of thorns (COTs) sea star *Acanthaster planci*, which has been a major factor in coral cover decline on the Great Barrier Reef (De'ath *et al.* 2012; Sweatman *et al.* 2011), although not on inshore reefs. Most *A. planci* (corallivorous sea star, see coral reef section) larvae starve in conditions of chlorophyll $< 0.5 \mu\text{gL}^{-1}$. Above this level, there is a rapid increase of larval survival (Brodie *et al.* 2005). Coral restoration has been trialled in turbid inshore reefs in Singapore, with marginal success, but farmed corals that survived the initial 14 months had high growth rates and established persisting colonies (Bongiorni *et*



al. 2011). High turbidity areas (e.g. the inshore GBR) may be suitable only to heterotrophic coral species with effective self-cleaning capacity (De'ath and Fabricius 2010). This has yet to be trialled on the GBR; ultimately, fundamental water quality problems need to be resolved before serious restoration activities can be considered (De'ath and Fabricius 2010; Grech *et al.* 2013). On the GBR coast, the Reef Water Quality Protection Plan (<http://www.reefplan.qld.gov.au/>) was put in place in 2003, and regularly releases “Report Cards” to measure its performance. By 2011 there had been some improvements (Reef Water Quality Protection Plan Secretariat 2013), but clearly better cooperation between local, state and federal governments and coastal developers will be crucial to secure lasting improvements. On the inshore GBR, various water quality measures (especially turbidity and chlorophyll concentration) were found to be good predictor of changes in biotic variables, but authors cautioned that thresholds may change spatially and temporally (Collier *et al.* 2012; de Boer 2007).

Inshore reefs bear the brunt of increased macroalgal growth as one of the responses to declining water quality (De'ath and Fabricius 2010). These reefs have naturally low herbivore biomass, and it may be useful to introduce invertebrate grazers like sea urchins or trochus (Villanueva *et al.* 2010)– which already occur in low densities – this would need to be properly trialled on fenced-off tracts of reef, to test for unfavourable interactions and outcomes. The captive breeding and introduction of marine species may be possible for some – where larval rearing techniques have been developed, and species are introduced into parts of their existing ranges where they may have become scarce – but introductions have had varying effects on the receiving environments, from boosting biodiversity and restoring ecological function (Bellard *et al.* 2012) to becoming dangerous pests (Albins and Hixon 2008; Gaither *et al.* 2013).

Small islands of the Torres Strait

Many of the required strategies for adapting to climate change in the Torres Strait will ultimately protect both human populations and ecosystems.

Small islands, such as those that predominate in the Torres Strait, are vulnerable to sea level rise, seawater intrusion into freshwater lenses, increased storm intensity and elevated temperatures (Hilbert *et al.* 2014). Their small size, relatively large coastal zones and isolation compound these impacts through restricting migration options and maximising exposure to coastal impacts. Changes in fire regimes and new pest and weed incursions could also have a disproportionately large impact on island vegetation and fauna communities. With changes to species ranges, the Torres Strait islands could also act as stepping-stones for diseases and exotic pests arriving from the north.

Adaptation planning for the Torres Strait is primarily concerned with human communities, but a growing body of research is establishing critical baseline data from many Torres Strait species and ecosystems which have been relatively understudied to date. Human and ecological systems in the region are strongly interlinked. Torres Strait ecosystems are mostly very healthy and adaptations options are limited, focusing primarily on reducing current anthropogenic stressors. Some of the required adaptation strategies will help to reduce climate change impacts on human populations and ecosystems, but there will also be trade-offs such as communities having to relocate to higher ground and into areas currently occupied by fauna and flora communities.

For islands large enough to benefit from conservation actions, adaptation measures will be similar to those described for coastal assemblages turtles, dugongs, seagrass beds and coral reefs.

Unlike mainland coasts, coastal communities migrating away from a shoreline affected by sea level rise on small islands will very rapidly run out of space, and simply disappear (Green *et al.* 2009). Coral cays may initially experience some growth as sea levels rise, but in the longer term this is likely to be overtaken as the rate of rise increases. Given a group of small islands such as the Torres Strait, identifying refugia and future habitat may therefore need to include identifying “sacrificial” islands for which nothing can be done. For those that can benefit from conservation actions,

adaptation measures will be similar to those described for coastal assemblages turtles, dugongs, seagrass beds and coral reefs (see Turtles, Dugongs and Coral reefs sections above). Adaptation measures will need to be applied on an island by island basis (Figure 2.6) (Duce *et al.* 2010). In some cases, soft adaptation measures such as beach and mangrove revegetation, beach and berm nourishment will be preferable to most expensive options such as building hard erosion control structures (Duce *et al.* 2010). However, for many islander communities living in the coastal hazard zone on low-lying islands, seawalls are the only viable short to mid-term option to reduce the impacts of inundation and erosion.

As with the GBR coast, reducing local impacts to coral reefs and seagrass beds will enhance their resilience to climate change effects. Turtle egg harvesting is a culturally important activity that poses an additional threat to turtles nesting in the Torres Strait; moving egg harvesting activities to areas where the sand has exceeded the threshold for hatchling survival may be a further adaptation measure to protect nesting turtles (Fuentes *et al.* 2010a).

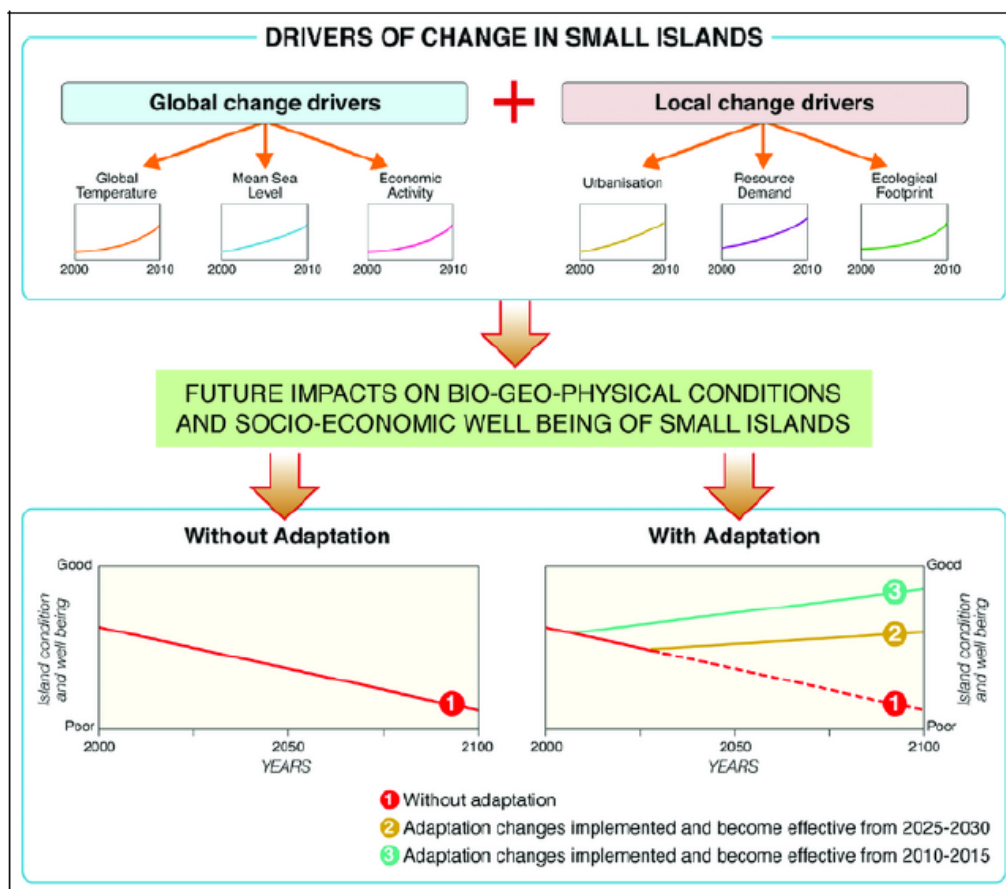
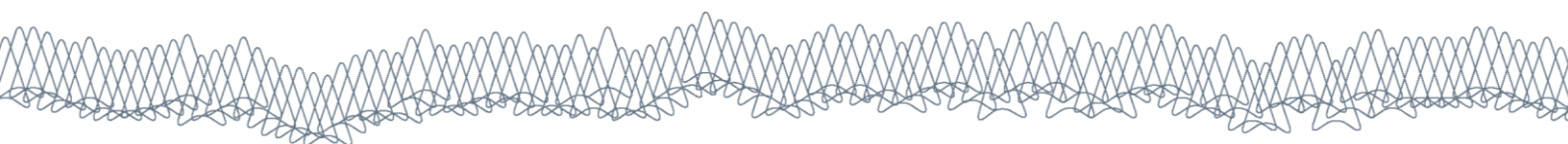


Figure 2.6 Drivers of change and potential consequences of different adaptation options specific to small islands

Source: Duce *et al.* (2010)



Flying foxes

Due to their flying large distances, adaptation strategies for flying foxes will need to be considered via a whole-landscape approach.

Australia's mainland flying-foxes (Chiroptera: Pteropodidae, *Pteropus* spp.) are large, highly mobile, flying mammals capable of travelling more than 20 km in one night (Markus and Hall 2004; Parsons *et al.* 2006) and hundreds of kilometres whilst migrating (Tidemann and Nelson 2004; Webb and Tidemann 1996). Therefore, adaptation strategies need to be considered via a whole-landscape approach. Flying-foxes are susceptible to extreme temperatures, and adaptation options during extreme heat waves include spraying camps with water to aid evaporative cooling (Welbergen *et al.* 2008). Range expansions and contractions have been shown and suggested in both the black flying-fox *Pteropus alecto* and the grey headed flying-fox *Pteropus poliocephalus* (Parsons *et al.* 2010; Roberts *et al.* 2012) but have not been shown as being attributable to climate change (Roberts *et al.* 2012).

The increasing urbanisation of flying-fox camps will need to be managed through public education and when non-lethal dispersals occur; the impacts will need to be closely monitored

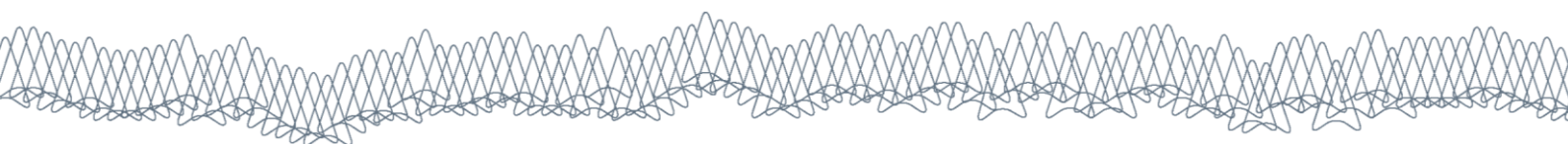
Flying-fox camps have increasingly been found in urban areas, resulting from the growth of urban areas into existing camps and from flying-foxes establishing new camps in urban areas (for example, the Royal Botanic Gardens, Melbourne)(Parris and Hazell 2005; van der Ree *et al.* 2006; Williams *et al.* 2006a). It has been suggested that new camps being established in urban areas is a result of the urban heat island effect (Parris and Hazell 2005) and urban planting providing access to reliable, year round resources (Williams *et al.* 2006a). The increased presence of camps in urban environments has led to conflict in these communities. These conflicts result from public health concerns about virus transmission and complaints about noise, smell and tree defoliation (Roberts *et al.* 2011; Thiriet 2005, 2010). As a result, the non-lethal dispersal of camps has been attempted at a number of sites using noise, light,

smoke, smell and roost modification (Roberts *et al.* 2011).

The long-term effect of dispersal attempts on flying-foxes is not known but regulations in regard to the timing of dispersals attempts to minimise the impact on populations. Spectacled flying-foxes *Pteropus conspicillatus* in the Wet Tropics region have recently had an increased number of dispersal attempts as a result of state government reforms. This is despite the species being listed as vulnerable (EPBC 1999). The impact that these dispersals have at the population level is unknown but dispersals can result in abandoned young, aborted fetuses and stresses on individuals (Thiriet 2005). Educating the community about human health risks and ways to live with flying-foxes could result in a reduction in dispersal attempts. In instances where dispersal is deemed necessary, the population will need to be closely monitored and dispersal ceased when mortality and/or injury occurs.

The greatest limiting factor for flying-fox persistence in the future is the quality and availability of food resources. Adaptation planning for these species should start with a good understanding of spatial and temporal resource distribution.

All four Australian mainland flying-foxes rely on a continuous temporal sequence of flowers and fruit (Eby and Law 2008; Parsons *et al.* 2006) and their success in Australia's patchy landscape has been attributed to their capacity to travel great distances to exploit resources and their adaptable diet (Birt *et al.* 1997). With predicted increases in temperature, CO₂ in the atmosphere and in particular precipitation seasonality (Pachauri and Reisinger 2007), the availability, nutritional quality, and distribution of plant resources is predicted to change (Hughes 2003; Lawler *et al.* 1997). The greatest limiting factor for flying-fox persistence in the future is the quality and availability of these food resources. Currently, food shortages are faced by many flying-fox species in the winter and many habitats where winter forage is available have been heavily cleared or are not protected (Eby and Law 2008). Adaptation planning for these species should start with a good understanding of spatial and temporal resource distribution. Suitable foraging habitat needs to be



established through habitat restoration and protected areas, linked by migration corridors and is in proximity to suitable roosting habitat. Nectar mapping is available for Grey headed flying-foxes, *Pteropus poliocephalus* throughout their range in Victoria, New South Wales, ACT and Queensland (Eby and Law 2008).

Birds

Garnett *et al.* (2013) conducted a continent wide analysis of the effects of climate change on Australian birds, and identified species in the Wet Tropics bioregion and Cape York Peninsula as amongst the most likely to lose suitable climate space, as corroborated by earlier studies (Reside 2011; Reside *et al.* 2012).

Species-specific adaptation actions for birds will need to take into account ecology, but general management to increase the adaptive capacity of the entire WTC Region will benefit a suite of species.

A large number of at-risk endemic species overlap in location, such as in the Wet Tropics uplands rainforests, and thus general adaptation management actions such as identification of climate refugia, habitat restoration and control of introduced pest species should benefit a suite of species. The relatively intact landscapes of Cape

York Peninsula and the Wet Tropics uplands are the regions where most in situ adaptation (e.g. fire, weed and feral animal management) will need to occur, and where climate change refugia need to be identified (Garnett *et al.* 2013).

The most important adaptation actions for birds will be managing current stressors, and in situ management including refugia identification and protection. Expensive ex situ options such as captive breeding and assisted migration should be considered a last option.

The most cost effective method for conservation of avian species threatened by climate change will be in 'in situ', through identification and protection of climate refugia, and for the most threatened species, through specific management actions such as artificial nest site creation, and human-made microhabitat refugia such as nest boxes. For the most endangered birds, 'ex situ' actions including captive breeding will be necessary, though this should be considered a last option only if a species is unlikely to survive in the wild. Using the three categories for adaptation strategies for birds discussed in Garnett *et al.* (2013), and shown in Table 2.1, we develop case studies for adaptation pathways for two

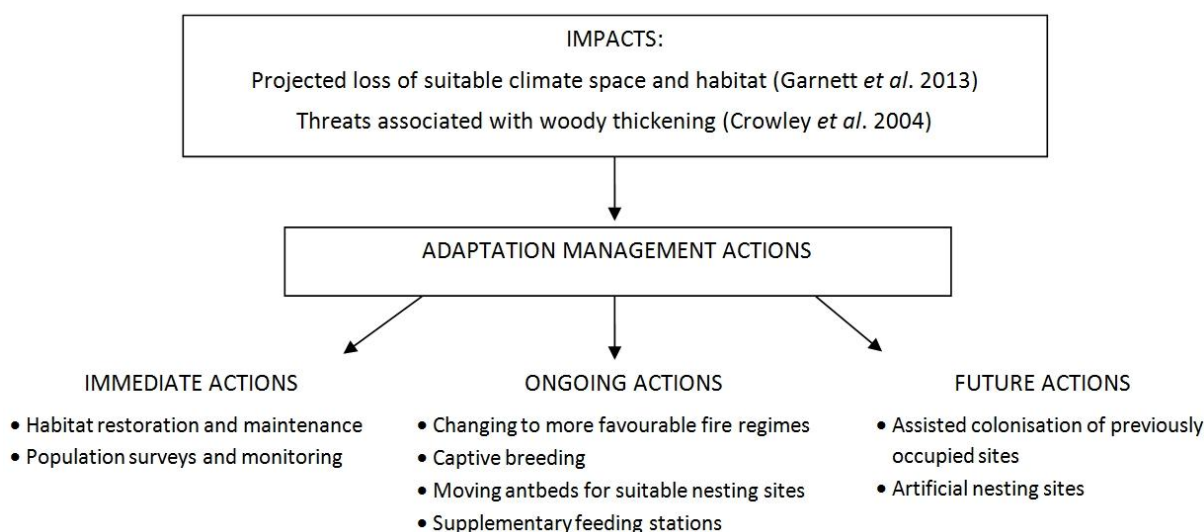
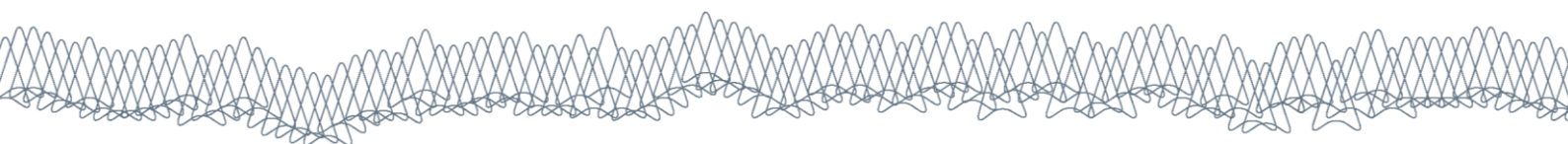


Figure 2.7 Adaptation Pathways – Case Study 1 – Golden shouldered parrot *Psephotus chrysopterygius*.



of the regions birds identified as being at high risk from climate change (Figure 2.7 and Figure 2.8).

The golden shouldered parrot is endemic to CYP and has been identified as being at high risk from climate change, having high sensitivity and high exposure (Garnett *et al.* 2013). It is also at risk from woody thickening, which has been associated with climatic change and CO₂ levels (Crowley *et al.* 2004). Immediate and ongoing actions listed above are already in place for this species, and management guidelines for its conservation are well established (i.e. Crowley *et al.* 2004). Future adaptation actions could include assisted colonisation and/or the possibility of developing artificial nesting sites.

The golden bowerbird is endemic to the high-altitude rainforest habitats of the Wet Tropics bioregion, and has long been identified as highly vulnerable to climate change due to its restricted geographical range and high ecological specificity (Garnett *et al.* 2013; Hilbert *et al.* 2014; Isaac *et al.* 2009; Shoo *et al.* 2005). Despite this, and in contrast to the Golden Shouldered Parrot, this species has no ongoing or planned conservation actions, and no management guidelines for its protection exist; it is currently listed as ‘least concern’ internationally and regionally (IUCN and DEHP Queensland). However, species surveys have been conducted for more than two decades (Williams *et al.*

2010), and modelling of climate change refugia in the WTC Region is ongoing. This species has been highlighted as one for whom assisted colonisation may be required in the future (Thomas 2011).

Cassowaries

Landscape connectivity will greatly improve the cassowary’s chances of survival.

Improving landscape connectivity and building resilience will be key strategies to ensure that cassowaries have the capacity to adapt to shifting climatic zones (National Biodiversity Strategy Review Task Group 2009). The spatial adaptation strategies need to be focused on the 8 identified priority key areas in the WTC Region as identified in the recovery plan (Latch 2007). Suggested methods include:

- increasing the connectivity between ecosystem networks on a large spatial scale
- protection of sites in parts of the species’ range where the climate is predicted to remain suitable over time
- isolated cassowary habitat that is within the new suitable climate zones will need to be linked to the nearest climate-proof and functional habitat network

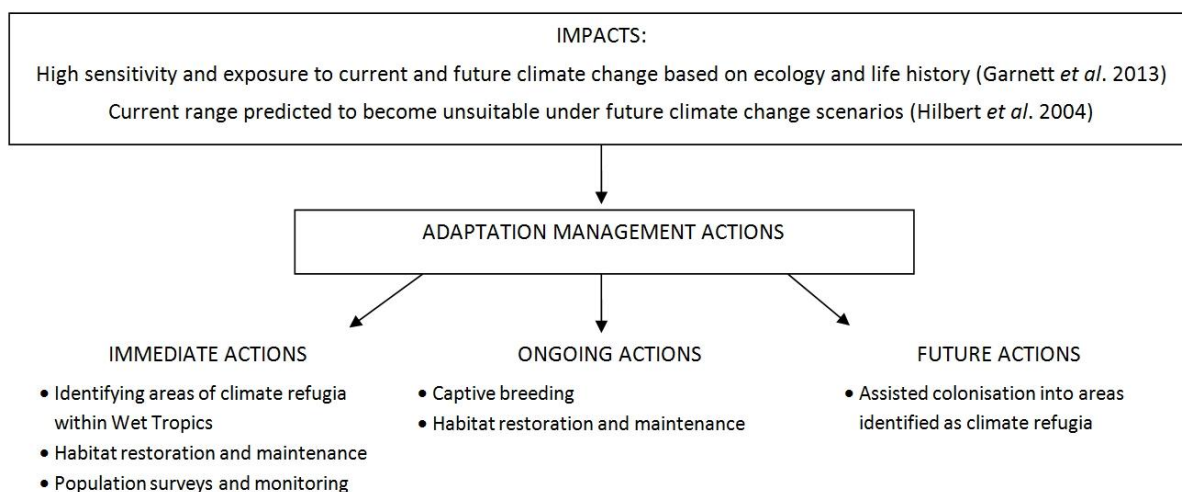
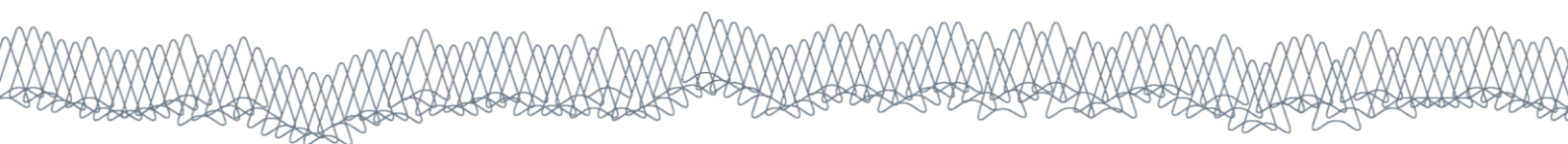


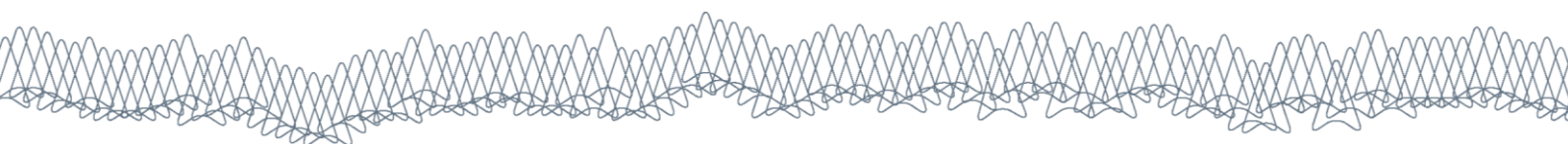
Figure 2.8 Adaptation Pathways – Case Study 2 – Golden Bowerbird *Prionodurus newtoniana*



- optimise sustainable networks in climate refugia, the part of the cassowary's range where the climate remains stable
- increase colonising capacity in parts of the habitat network that remains suitable in future climate scenarios
- inclusion in (and updating) of the Recovery plan for the southern cassowary *Casuarius casuarius johnsonii* (Latch 2007) of treatment for the potential effects of climate change as well as inclusions as a threat specifically for the cassowary in the Back on track Actions for biodiversity plans (Department of Environment and Resource Management 2010)
- implement strategies to conserve cassowary habitat on private lands, nature refuges
- promote co-management of areas with Indigenous people (particularly coastal lowlands).

Additionally, monitoring the populations and abundance of cassowaries is crucial to their successful management.

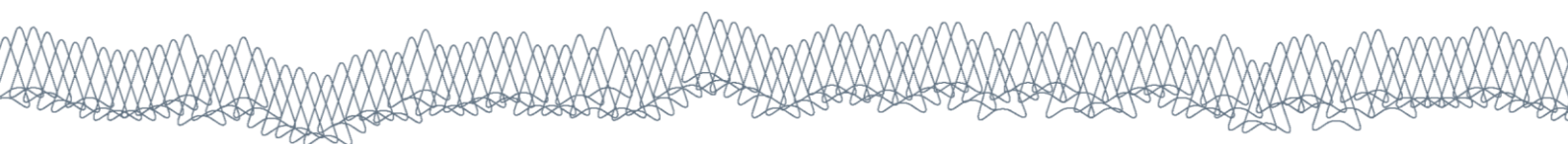
Other suggested strategies at the property level are provided by the Queensland Government's Department of Environment and Heritage Protection - <http://www.ehp.qld.gov.au/wildlife/threatened-species/endangered/endangered-animals/cassowary.html>.



Summary of adaptation options for biodiversity

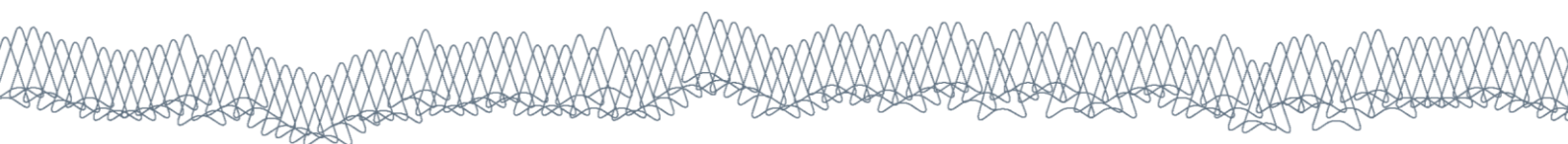
Table 2.8 Major impacts of climate change on biodiversity and potential adaptation options. Adaptation options that also potentially mitigate greenhouse gas emissions are marked **(M)**.

EXAMPLE ADAPTATION OPTIONS				
Climate change	Major impacts	Protect	Accommodate	Retreat
Combined climate change effects	1. Areas within species' current geographic distribution will become unsuitable.		<ul style="list-style-type: none"> Identify, conserve and restore refugia, especially those that protect from multiple impacts, and for species not currently occurring in the WTC region; Promote functional connectivity at all spatial scales to aid species in accessing resources and refugia (M); Use 'composite provenancing' of seeds in restoration; Adapt fire, weed and feral animal management to promote in situ; Create artificial microhabitats. 	<ul style="list-style-type: none"> Assisted colonisation to new or historic locations; Assisted interbreeding between populations; Seedbanking
	2. Small islands are vulnerable to impacts and have limited migration opportunities.		<ul style="list-style-type: none"> Manage trade-offs, e.g., relocation of human communities to areas that are currently in natural state. 	<ul style="list-style-type: none"> Identify 'sacrificial islands' for which conservation adaptation options are severely limited.
Increased average temperatures	1. Exceed thermal tolerances of terrestrial species, marine and coastal communities; leading to reduced survival, growth and reproduction in parts of current range.		<ul style="list-style-type: none"> Conserve thermal refugia within species' current distributions; Conserve or improve functional connectivity with thermal refugia (M); Assisted gene flow with populations on 	<ul style="list-style-type: none"> Conserve thermal refugia outside species' current distributions; Conserve or improve functional connectivity with thermal refugia (M); Assisted translocation;

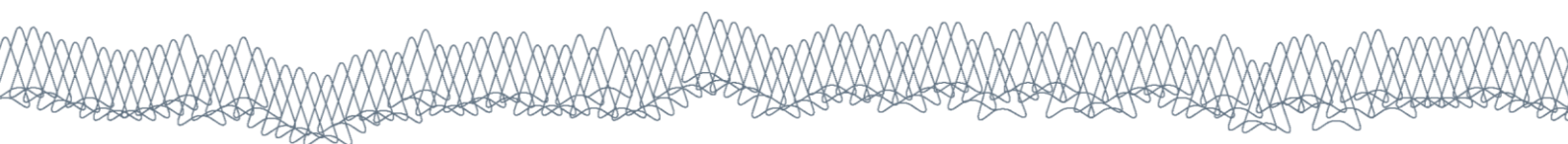


EXAMPLE ADAPTATION OPTIONS

			· 'hot periphery' of current distribution.	· Ex-situ conservation.
2.	Exceed thermal tolerance of coral reef organisms		<ul style="list-style-type: none"> · Manage existing threats to inshore reef water quality, e.g., high sedimentation rates; · Identify and enhance connectivity to refugia; · Trial introduction of invertebrate herbivores to limit macroalgal growth. 	· Translocation of corals to higher latitudes.
3.	Changed fire frequency, intensity, extent and timing	Active management to exclude fire from some systems (M) .	<ul style="list-style-type: none"> · Active fire management to promote desired vegetation communities (M); · Conserve fire refugia within species' current distributions; · Conserve or improve functional connectivity with fire refugia (M). 	<ul style="list-style-type: none"> · Conserve fire refugia outside species' current distributions; · Conserve or improve functional connectivity with fire refugia (M); · Ex-situ conservation.
4.	Increased survival, growth and reproduction of certain species, potentially including introduced species		· Management intervention to remove undesirable species and mediate negative impacts.	
5.	Impacts on freshwater ecosystems		<ul style="list-style-type: none"> · Preserve or restore riparian vegetation cover (M); · Preserve and enhance ground water flows by minimising fine sediment input. 	
6.	Immigration of plants and animals from other regions		<ul style="list-style-type: none"> · Conserve thermal refugia for species from other regions; · Conserve or improve functional 	· Ex-situ conservation.

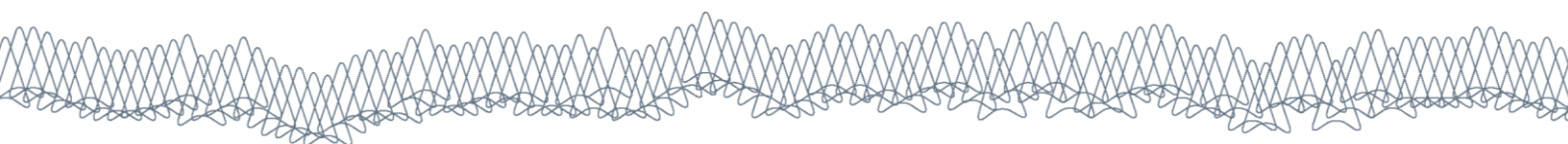


EXAMPLE ADAPTATION OPTIONS				
			connectivity with thermal refugia for species from other regions (M) .	
Sea level rise	1. Sea water inundation of fresh water bodies in coastal areas; Increased tidal reach in coastal watercourses	Sea walls, dykes, storm surge barriers; drainage channels, tidal gates	<ul style="list-style-type: none"> Conserve freshwater refugia within species' current distributions; Conserve or improve functional connectivity with freshwater refugia. 	<ul style="list-style-type: none"> Conserve freshwater refugia outside species' current distributions; Conserve or improve functional connectivity with freshwater refugia; Ex-situ conservation.
	2. Loss of turtle nesting beaches	<ul style="list-style-type: none"> Construct sea walls, groynes, beach nourishment and dune building . 	<ul style="list-style-type: none"> Conserve landward buffer zones around current nesting beaches. 	<ul style="list-style-type: none"> Move nests from areas of inundation and erosion; Ex situ conservation.
	3. Sea water inundation of coastal vegetation communities		<ul style="list-style-type: none"> Conserve landward sea level rise refugia within ecosystems' current distribution; Conserve or improve functional connectivity with sea level rise refugia (M). 	<ul style="list-style-type: none"> Conserve landward sea level rise refugia outside ecosystems' current distribution; Conserve or improve functional connectivity with sea level rise refugia (M); Ex-situ conservation.
	4. Impacts on freshwater ecosystems		<ul style="list-style-type: none"> Conserve, restore or enhance vegetation buffers to storm surges 	
Extreme events (increased occurrence of high intensity cyclones, extreme rainfall events, heatwaves)	1. Physical damage to terrestrial, freshwater and marine systems due to high winds, wave action and storm surge.		<ul style="list-style-type: none"> Management intervention to assist post-cyclone recovery. 	
	2. Damage to coral reefs and other marine systems through freshwater pulses and pollutant runoff	Physical structures to mediate freshwater pulses.	<ul style="list-style-type: none"> Improve water quality management of inshore reef areas via catchment management actions (e.g., around ports); Improve restoration 	

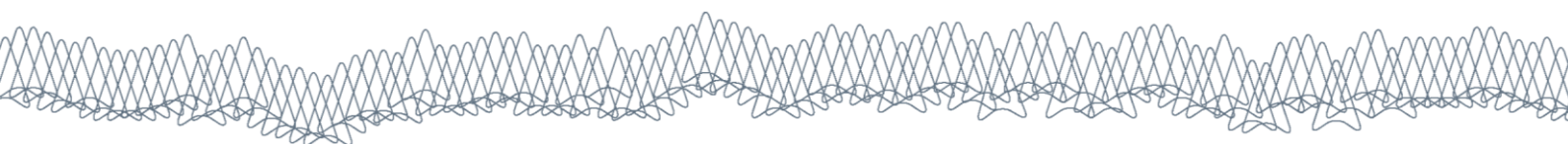


EXAMPLE ADAPTATION OPTIONS

			<ul style="list-style-type: none"> of coral reefs; Reduce other immediate anthropogenic impacts. 	
	3. Increased sedimentation of seagrasses, reducing feeding areas for dugongs		<ul style="list-style-type: none"> Control sediment and nutrient runoff control; Reduce anthropogenic mortality. 	
	4. Thermal tolerances of animal species exceeded during heatwaves, leading to reduced survival		<ul style="list-style-type: none"> Conserve heatwave refugia within species' current distributions; Conserve or improve functional connectivity with heatwave refugia (M); Manage acute impacts, e.g., by spraying flying-fox camps with water. 	<ul style="list-style-type: none"> Conserve heatwave refugia outside species' current distributions; Conserve or improve functional connectivity with heatwave refugia (M); Ex-situ conservation.
	5. Coral bleaching during heatwaves events	<ul style="list-style-type: none"> Sun-shading 	<ul style="list-style-type: none"> Restoration of coral reefs; Conserve heatwave refugia within current coral reef system; Transplant heat-tolerant coral species. 	<ul style="list-style-type: none"> Conserve heatwave refugia outside current coral reef system; Conserve or improve functional connectivity with heatwave refugia.
	6. Increases in invasive species following disturbances		<ul style="list-style-type: none"> Prioritise control of species expected to exert highest threat, including new invasive species. 	
More variable rainfall	1. Changed patterns of plant and animal species' patterns of growth and reproduction		<ul style="list-style-type: none"> Conserve hydric refugia within species' current distributions; Conserve or improve functional 	<ul style="list-style-type: none"> Conserve hydric refugia outside species' current distributions; Conserve or improve functional



EXAMPLE ADAPTATION OPTIONS				
			connectivity with hydric refugia (M) ; · Assisted gene flow with populations on drier or wetter peripheries of current distribution.	connectivity with hydric refugia (M) ; · Assisted translocation; · Ex-situ conservation.
	2. Impacts on fire regime, together with impacts of increased CO ₂ on fuel loads		· Implement integrated fire management regimes, with attention to timing, intensity, frequency and extent of burning.	
	3. Impacts on freshwater ecosystems		· Ensure provision of environmental flows; · Maintain hydraulic habitat complexity.	
Increased ocean acidification	1. Damage to coral reef systems and organisms		· Selective breeding of tolerant stock; · Modification of sea water (e.g., alkalinity).	



Monitoring adaptation outcomes

Adaptation actions will require monitoring to ascertain whether they have produced desirable outcomes and to inform changes that may be required; ideally, monitoring would be embedded within an adaptive management framework.

Based on recent reviews on the quality and outcomes of monitoring programs, Lindenmayer *et al.* (2012a) provided a set of guidelines for the implementation of monitoring programs in the future. Effective monitoring programs should:

1. deliver information on trends in key aspects of biodiversity (e.g. population changes)
2. provide early warning of problems that might otherwise be difficult or expensive to reverse
3. generate quantifiable evidence of conservation successes (e.g. species recovery following management) and conservation failures

4. highlight ways to make management more effective
5. provide information on return on conservation investment.

Below are a set of principles and considerations for successful monitoring programs.

Monitoring programs should be initiated with a specific objective, or set of objectives, in mind.

Optimal monitoring theory prescribes a decision-making framework in which management and monitoring are 1) decided and designed, 2) implemented, 3) monitored, 4) evaluated, and 5) adapted according to explicit objectives and budget constraints (Gerber *et al.* 2005). The objectives of monitoring will inform what should be measured (Lindenmayer *et al.* 2012a).

Monitoring should be embedded within an adaptive management framework that involves scientists, management agencies, funding agencies and government.

A successful monitoring program informs management

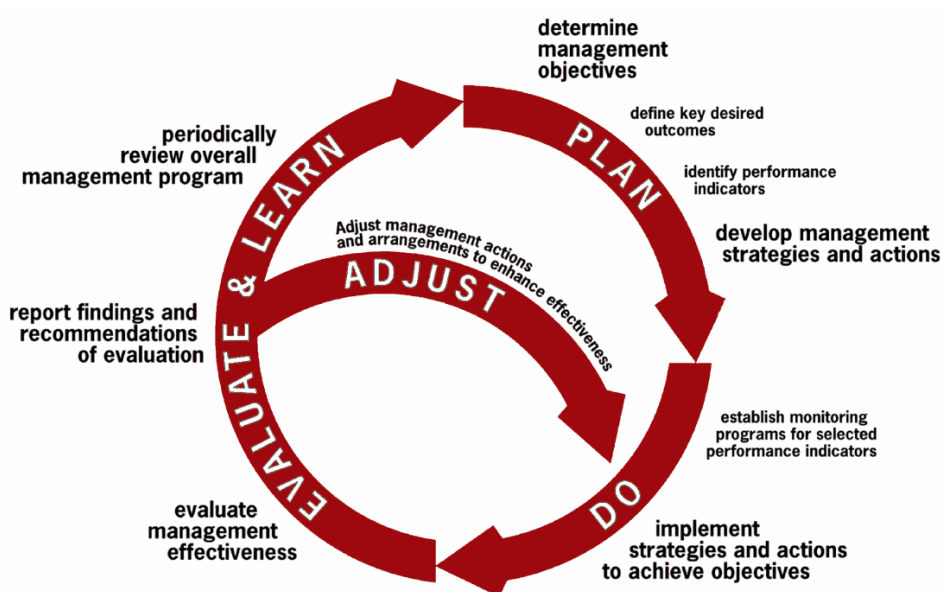
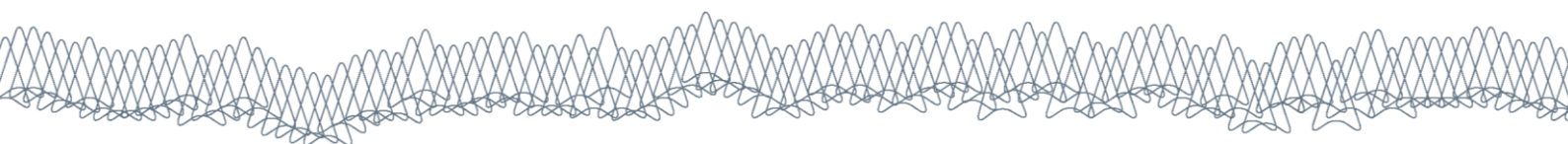


Figure 2.9 Example of an adaptive management cycle

Source: <http://www.cmar.csiro.au/research/mse/>.



about parameters relative to objectives; usually change in one or more indicators (Gerber *et al.* 2005). This then triggers changes in management actions by highlighting environmental or ecological conditions that may indicate the limitations of current management practices (Werners *et al.* 2013). While best outcomes can be achieved if such trigger values are defined before the start of a program, this requires sound predictions of ecosystem responses to either the management action or the threat the action is supposed to mitigate (Figure 2.9). Methods for allocating resources optimally in monitoring are also ideally embedded within the adaptive management framework (Field *et al.* 2007), especially when it comes to allocating funding between monitoring and other management actions (Regan *et al.* 2005). The cost of monitoring, monetary benefits for users, the cost of management and economic discounting of profit are all considered (Gerber *et al.* 2005).

The power to detect changes depends on the sampling design, methods, timing and frequency of the monitoring program.

Whilst the specific methods are variable between ecosystems, they generally seek to balance the need for the power to detect change (which usually means more time, samples, equipment, personnel) and budgetary constraints (which usually means less of the above). It is recognised that there is a need to invest in long-term monitoring, in adequate data storage and reporting mechanisms, in ongoing training for emerging ecologists to continue the monitoring effort in the long term and in continuously updating monitoring methods as new technology emerges (Lindenmayer *et al.* 2012a). Citizen science is emerging as a low-cost option for long-term monitoring that additionally has the benefit of educating and engaging the public (Tulloch *et al.* 2013).

Communication is the key link in all steps of embedding monitoring within an adaptive management framework.

Scientists have been notoriously reluctant to translate scientific findings into clear and simple messages for the public, managers and policy makers, and to give

clear and constructive advice on what actions should be taken. However, it is increasingly recognised that this kind of communication is equally, if not more, important to publishing results in scientific journals. Monitoring programs and resulting conservation actions are in need of political and public support, in order to generate the political will to find and secure funding for long-term monitoring programs (Lindenmayer *et al.* 2012a).

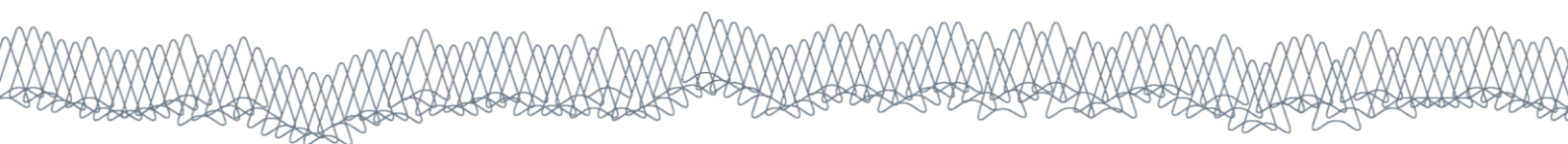
Summary and conclusions

Barriers to climate change adaptation

Ignorance and misinformation of the general public is a major obstacle at all levels, leading to disinterest and inertia, and supporting a continued lack of political will. Monetary cost is the most common perceived barrier to adaptation actions.

A number of obstacles exist in the implementation of actions to assist the adaptation of WTC Region biodiversity to climate change, including competition for land, physical limits of organisms, knowledge gaps, cost of actions, existing markets, and social perceptions (Boulter 2012; Garnett *et al.* 2013). We need to alter political and public perceptions that ecosystem conservation and restoration incur a net cost. If ecosystem services were given a monetary value, in almost all cases restoration would, in fact, result in a net benefit (De Groot *et al.* 2013). Furthermore, resource allocation algorithms were recently developed for incorporating climate change into the prioritisation of areas for conservation (Iwamura *et al.* 2010). This highlights the need for much more intensive and targeted education of the public about ecosystem services that support our quality of life, the long-term consequences of ecosystem change, and the long-term value of ecosystem adaptation.

All conservation actions have costs associated with them, and adaptation to climate change will also incur costs. Projecting the ongoing costs of adaptation into the future is challenging, but the relative expenditure for different actions may be predictable based on current costs (Garnett *et al.* 2013). Generally, manipulative rehabilitation options (reforestation,



building or engineering structures, relocation species) are more expensive than passive options (protected areas, management of particular human actions).

Conservation messages fail to capture the role of market mechanisms in persuading the public and governing bodies of the benefit and urgency of climate change adaptation.

Burley *et al.* (2012) take a significant step to include financial incentives as ‘soft’ adaptation options (Table 2.4). Ultimately, the use of these options would need to be tailored to specific locations, as human communities have slightly different drivers of environmental values and would therefore respond to different incentives. This is likely to be the case in the WTC Region, where communities range from urban centres (e.g. Cairns) to isolated and remote island communities (e.g. the Torres Strait).

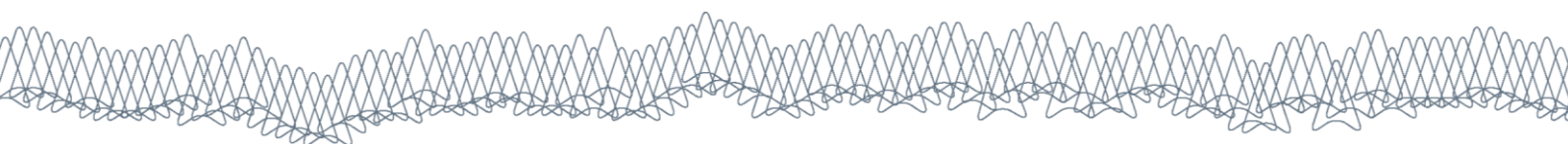
- The Productivity Commission’s report on barriers to adaptation further summarised the most important recommendations for effective adaptation (Productivity Commission 2012)
- Governments at all levels should:
 - embed consideration of climate change in their risk management practices
 - ensure there is sufficient flexibility in regulatory and policy settings to allow households, businesses and communities to manage the risks of climate change
- A range of policy reforms would help households, businesses and governments deal with current climate variability and extreme weather events. These reforms would also build adaptive capacity to respond to future climate impacts. Examples include:
 - reducing perverse incentives in tax, transfer and regulatory arrangements that impede the mobility of labour and capital
 - increasing the quality and availability of natural hazard mapping
 - clarifying the roles, responsibilities and legal liability of local governments, and improving their capacity to manage climate risks

- reviewing emergency management arrangements in a public and consultative manner
- retain all existing habitat
- to better prepare for natural disasters and limit resultant losses
- reducing tax and regulatory distortions in insurance markets
- Further actions are required to reduce barriers to adaptation to future climate trends and to strengthen the climate change adaptation policy framework. These include:
 - designing more flexible land-use planning regulation
 - aligning land-use planning with building regulation
 - developing a work program to consider climate change in the building code
 - conducting a public review, sponsored by the Council of Australian Governments, to develop appropriate adaptive responses for existing settlements that face significant climate change risks
- Some measures should not be implemented, as the costs would exceed the benefits:
 - Household insurance subsidies, or insurance regulations that impose net costs
 - Systematically reviewing all regulation to identify impediments to adaptation
 - Mandatory reporting of adaptation actions
- Some individuals and communities are likely to face greater challenges in adapting than others, implying a role for the tax and transfer system.

Concluding remarks

Some of the over-arching messages pertaining to the adaptation of biodiversity to climate change are fairly consistent across the different ecosystem types, species and processes. Consistent messages include:

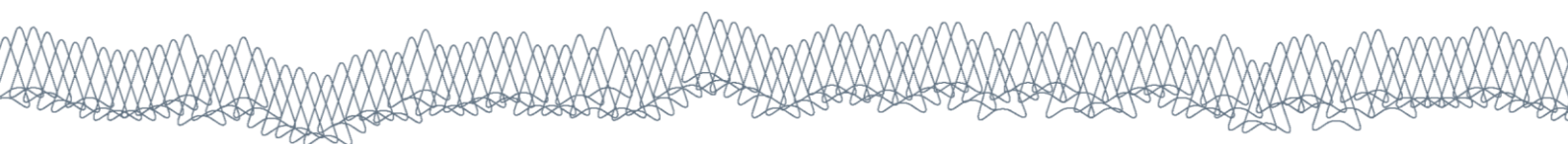
- The threat of climate change is unlike many of the current threats to species and ecosystems; however,



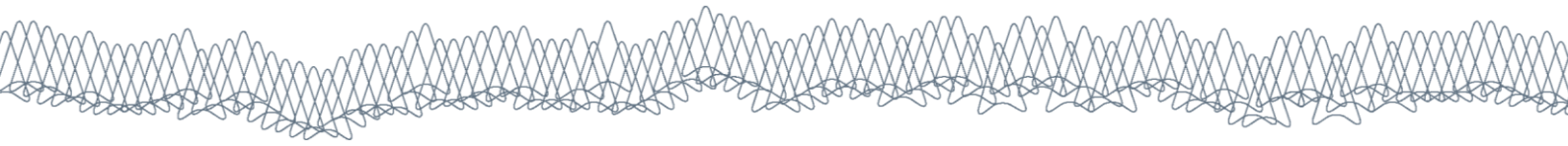
- In many cases, management actions for climate change are similar to what is being conducted currently, or currently known to be important.
- Managing for climate change will need to involve facilitating change, in particular,
- Facilitating the movement of species and ecosystems as they track suitable climate and conditions. In addition:
- “In situ” conservation – managing species in their habitat, or facilitating their dispersal, will be less expensive than “ex situ” conservation, which will be far more resource-intensive.

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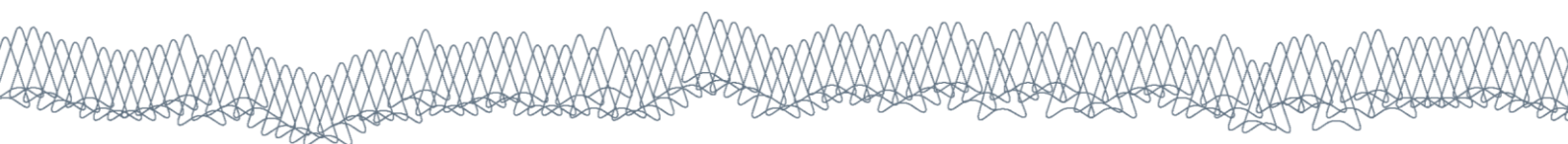
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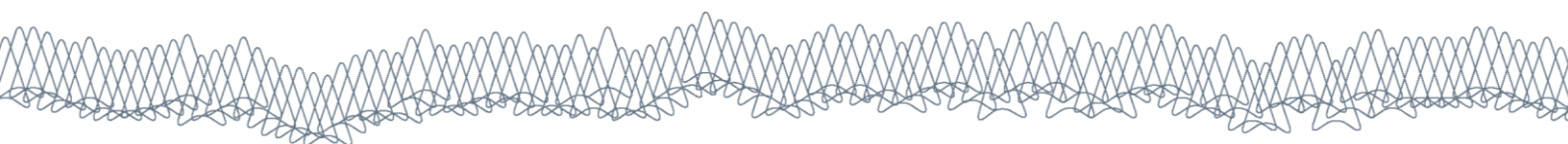
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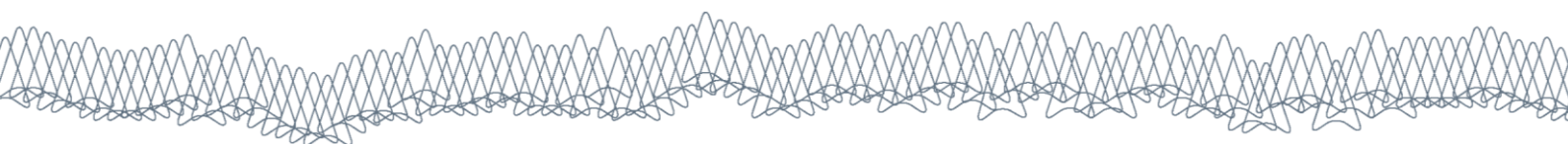
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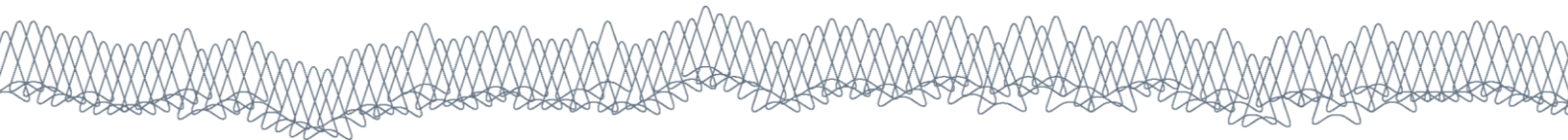
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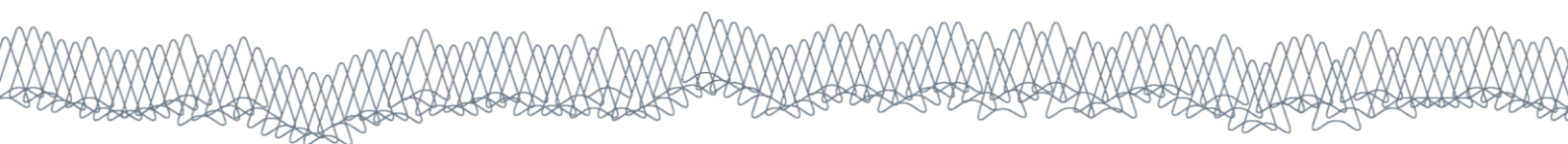
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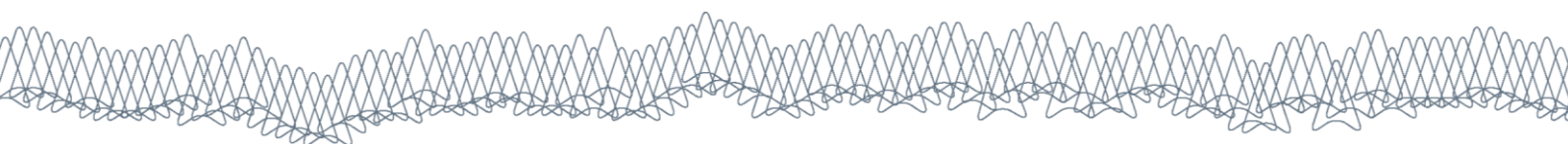
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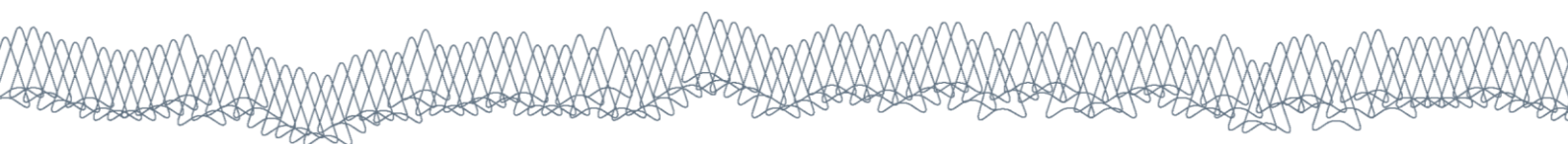
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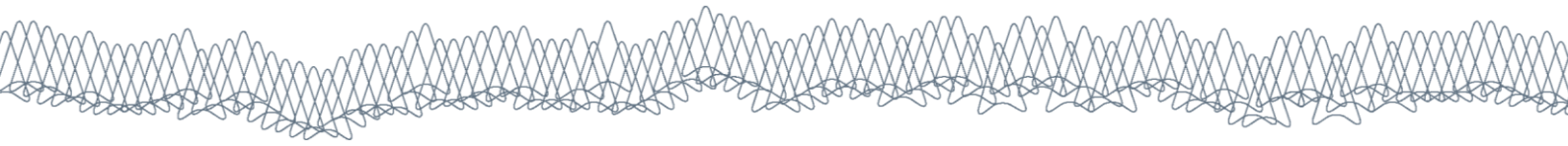
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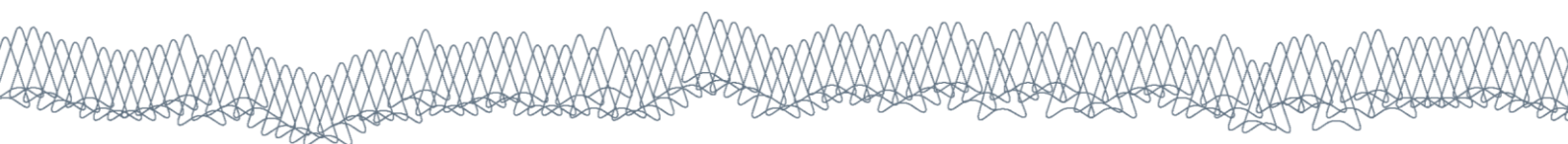
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3. Ecosystem services: adaptation pathways and opportunities

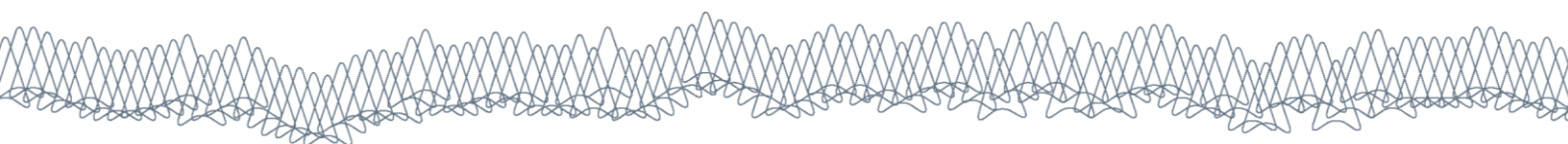
Mohammed Alamgir, Edison M. Salas, Stephen M. Turton and Petina L. Pert

IN A NUTSHELL
<ul style="list-style-type: none"> • An appropriate system for payment for ecosystem services is required. • Carbon abatement projects are influenced by national and international pricing and trading schemes. Abatement projects are currently limited by frequent policy shifts, a lack of funding and complexity in approaches. Carbon plantings have the potential to mitigate CO₂ as well as to provide wildlife habitat, increase landscape functional connectivity & protect water quality. • Integrated farm management has the potential to deliver benefits for biodiversity conservation, ecosystem service provision and farm productivity.

Precis

In this chapter, we compile climate change adaptation options for ecosystem services for the Wet Tropics Cluster (WTC) region, derived from the Australian literature and elsewhere. We focus particularly on water regulation, climate regulation, carbon sequestration, agricultural production, timber production, habitat provision, erosion control, and traditional values. We also discuss emerging opportunities that may become available in WTC region in the future, bring together the limitations and constraints of current payments for carbon abatement and discuss possible ways to establish payments for ecosystem services through examination of examples from across the world that may be applied to the WTC region. Finally, we discuss the barriers to climate adaptation in regard to ecosystem services. The key messages associated with each of the topics addressed in this chapter are:

TOPIC	KEY MESSAGES
Introduction	70. Natural ecosystems have a low adaptive capacity in the face of rapid climate change. 71. Both short- and long-time planning are required.
Water regulation and water provision	72. Management practices that maintain or restore ground cover & riparian vegetation are required for protection of water quality. 73. Water sensitive design at both macro- and micro-scales is required.
Coastal protection and erosion control	74. Protection and landward facilitation of mangroves are both necessary for coastal protection from tropical cyclones, storm surges, sea-level rise and salinity intrusion. 75. Restoration of littoral forests will reduce the vulnerability of coastal communities to extreme climate events like tropical cyclones, storm surges and sea-level rise and will potentially minimise coastal erosion. 76. Coastal plantations with robust native tree species will build resilience to anticipated increases in tropical cyclone wind speeds and storm surge threats. 77. Hybrid engineering will be useful in places where natural ecosystem-based protection is not sufficient or feasible.



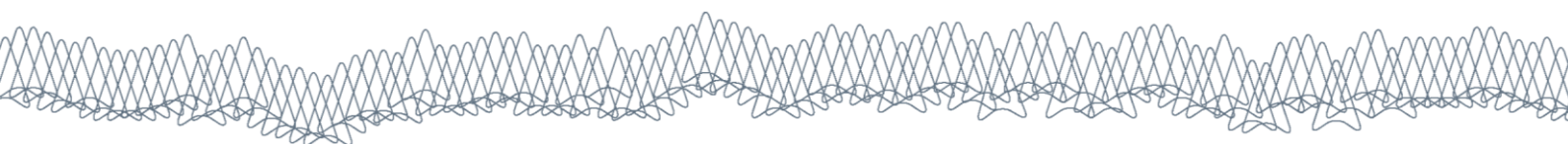
TOPIC	KEY MESSAGES
	78. Re-establishing native vegetation in beaches, dunes and barrier Islands will increase the climate adaptation potential of these systems.
Carbon sequestration	79. There is high potential for more carbon sequestration and storage through improved management practices, environmental planting, mixed farming and land rehabilitation. 80. Native species with relatively high wood density and slow growth rates are more likely to store carbon for a long time. 81. There should be consideration of potential limitations to C sequestration on rangelands.
Habitat provision for biodiversity	82. Integrated farm management has potential benefits for biodiversity as well as farm productivity. 83. Ongoing and enhanced invasive species management is required.
Timber provision	84. More emphasis on cyclone-resistant tree species is required. 85. Forest management practices may affect climate change resilience. 86. Opportunities to increase growth rates due to elevated CO ₂ should be taken advantage of where practical.
Traditional values	87. Incorporating local and Indigenous knowledge in formal decision-making about ecosystem services and climate change adaptation is important. 88. Enhancing Indigenous adaptation options and community-based adaptation is useful. 89. Strong linkages between local knowledge and formal science are required.
Marine ecosystem services	90. Maintaining continuous native vegetation cover in the terrestrial ecosystems will reduce some stressors on the Reef and will increase its resilience to climate change.
Barriers in current mechanisms	91. Lack of sufficient funding is an ongoing concern. 92. Frequent government policy shifts are not helpful. 93. Complexity of methods and approaches is discouraging for many stakeholders. 94. Uptake of adaptation measures depend on attitudes beliefs and perceptions about climate change by members of the society and their level of exposure to mass media.
Mechanisms for establishing payments for ecosystem services	95. An appropriate process is required for payment for ecosystem services.

Introduction

Natural ecosystems have a low adaptive capacity in the face of rapid climate change.

Both short- and long-time planning are required.

Ecosystem services are the benefits people derived from ecosystems (MA 2003, 2005) including the provision of food, fibre, timber and water, climate regulation, nutrient cycling, and habitat provision for biodiversity. Ecosystem services are an essential element of community wellbeing but are under serious threat from global climate change (Stafford Smith & Ash 2011; Pert *et al.* 2014) and from the current push for



economic development above social, cultural and environmental considerations by current state and federal governments (Pert *et al.* 2014). NRM managers will be required to respond at differing temporal and spatial scale to ensure the sustainable supply of ecosystem services (Lawler 2009).

Natural ecosystems have a high vulnerability to climate change because both their coping range and adaptive capacity are low. Thus even below a 2°C temperature change – relative to 1990 – there will be significant negative effects on natural ecosystems (Stafford Smith & Ash 2011). Therefore adaptation strategies should start as soon as possible. In addition to natural ecosystems, coastal communities and water security are highly vulnerable to climate change impacts (Stafford Smith & Ash 2011).

Decision making in the face of adaptation to climate change is difficult due to the uncertainty involved in the projected magnitude of climate change (Jones & McInnes 2004; Stafford Smith *et al.* 2011). It is even more difficult for the WTC region due to complex landscape features and various environmental gradients. Therefore, both short- and long-time decisions are required. For example, urgent decisions about water savings and storage measures are required, especially in northern parts of the WTC Region (Cape York and Torres Strait) that experience pronounced dry seasons. Lawler (2009) has pointed out a triage classification for ecosystems management under climate change threat considering value of ecosystems (ecological, economic and social value) and severity of climate change impacts (Figure 3.1). Some systems require immediate action otherwise they may be lost forever, for example rare systems or species, species with high interaction strength and in some systems-high priority only a few years waiting is possible before the management actions, if closely monitored. Other systems (low priority and no management) either require management actions in the long run or no management actions. These systems wouldn't be lost if there is no management actions soon. These systems require monitoring. Considering this classification, it is likely that for the WTC Region, immediate actions are required for many ecosystem services including coastal protection and erosion

control due to the projected and apparent severe tropical cyclone and associated impacts (IPCC 2013; Turton 2008, 2014) and habitat provision for biodiversity for iconic species due to projected habitat loss resulting from temperature rise and seasonal rainfall variability (Hilbert *et al.* 2001; Williams *et al.* 2003).

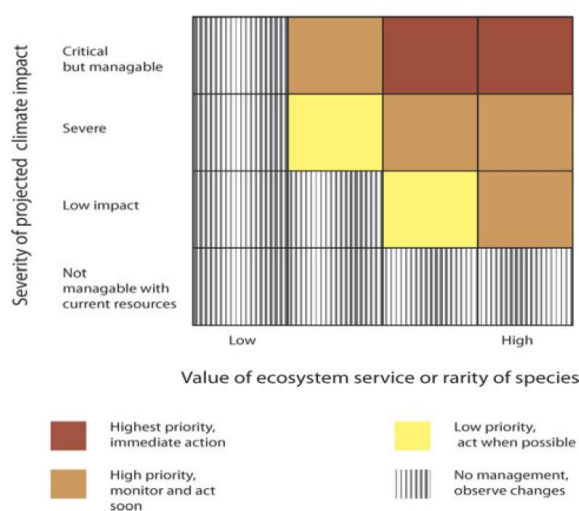


Figure 3.1 Triage classification for ecosystem services management in a changing climate

Source: adapted from Lawler (2009)

Specific ecosystem services

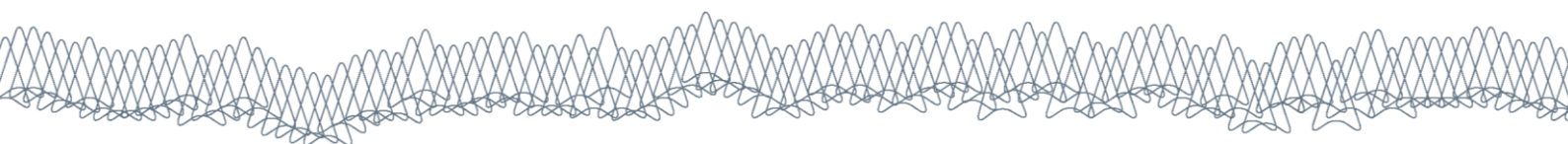
In this section we examine specific ecosystem services that are most relevant to the Wet Tropics Cluster region. Appendix 3.1 provides a summary for planners.

Water regulation and water provision

Management practices that maintain or restore ground cover and riparian vegetation are required for protection of water quality.

Water sensitive design at both macro- and micro-scales is required.

Both water regulation and water provisioning services are among the most important ecosystem services provided in the WTC region. It is well recognised that healthy upstream vegetation cover can deliver high



quality water in downstream environments, including the Great Barrier Reef lagoon (Calder *et al.* 2007). Upstream vegetation also has profound influences on regulating runoff and flood mitigation to downstream users (Baral *et al.* 2012). Fewer disturbances to vegetation cover will also reduce outside stressors so as to increase climate resilience. Woody vegetation – including mangroves – may also remove sediment and nutrient pollutants from runoff (Baral *et al.* 2012) eventually helping to maintain water quality.

Riparian vegetation has a profound influence on maintaining water regulation, water quality and water temperature. Riparian vegetation reduces stream temperatures and creates cool water refugia (Palmer *et al.* 2008; Scott *et al.* 2008). Riparian vegetation is likely to increase the ability of cold-water micro fauna to persist in rising temperature through protecting headwaters, and identifying and protecting existing thermal refugia (Hansen *et al.* 2003; Chapter 2, this report). Riparian vegetation also provides important habitat for many terrestrial fauna and flora and may provide functional connectivity through disturbed landscapes, enabling dispersal. A healthy riparian zone filters sediments and slow down overland water flow, which subsequently provides water quality benefits to the community (Burgman *et al.* 2007). The restoration of riparian vegetation is an important option for adaptation to climate change. Selection of trees species should include consideration of resilience to cyclones; after Severe Tropical Cyclone ‘Larry’ it was found that trees in riparian zones were more severely damaged than those in nearby forests fragments (Bruce *et al.* 2008).

Climate change is projected to lead to increased variability in rainfall and more intense extreme rainfall events in the WTC region (Turton 2014). This will potentially mean longer dry periods as well as more frequent, prolonged and extensive freshwater inundation events. Higher rates of evapotranspiration will interact with these changes and may exacerbate water shortages, especially during the dry season. A number of management actions are available to regulate water flow in stream channels such as flood plain restoration, channel reconfiguration and bank stabilisation. Creating off-channel basins and wetlands

to store water during extreme flows may prevent excessive downstream flows (Palmer *et al.* 2008). Groundwater extraction could also be an option to address water shortage in a changing climate although it is controversial (Hansen *et al.* 2003; Refer to Chapter 4, this report). During the dry season, water savings measures are essentially a good option particularly for the private use of water.

Coastal protection and erosion control

Protection and landward facilitation of mangroves are both necessary for coastal protection from tropical cyclones, storm surges, sea-level rise and salinity intrusion.

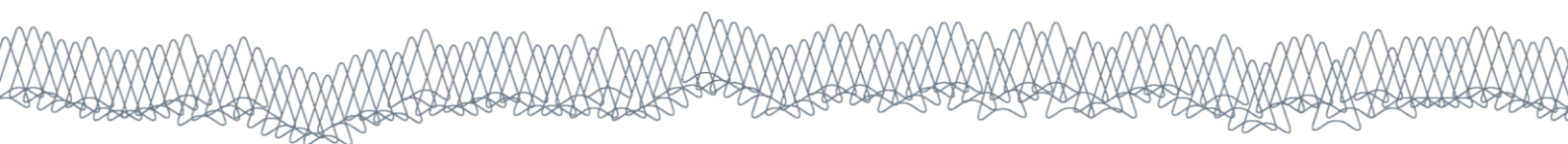
Restoration of littoral forests will reduce the vulnerability of coastal communities to extreme climate events like tropical cyclones, storm surges and sea-level rise and will potentially minimise coastal erosion.

Coastal plantations with robust native tree species will build resilience to anticipated increases in tropical cyclone wind speeds and storm surge threats.

Hybrid engineering may be a useful protective adaptation strategy in places where natural ecosystem based protection is not sufficient or feasible.

Re-establishing native vegetation on beaches, dunes and barrier Islands will increase the climate adaptation potential of these systems.

Mangroves provide coastal protection by reducing wave energy, increasing sedimentation, reducing erosion and movements of sediments, and reducing water velocities (Gedan *et al.* 2011; Shepard *et al.* 2011; Spalding *et al.* 2014). Mangroves are very efficient in trapping fine sediment particles (Wolanski 1995; Young & Harvey 1996). Mangrove roots also increase soil cohesion, and provide an important physical barrier between soil and water (Gedan *et al.* 2011). Wave heights can be reduced by 13% to 66% over 100 m of mangroves (McIvor *et al.* 2012a). Storm surge heights can be reduced between 4 to 48 cm/kilometre through provisioning of mangroves along the coast (Krauss *et al.*



2009; McIvor *et al.* 2012b; Zhang *et al.* 2012).

Therefore, mangrove protection and enhancement are both necessary pathways to adaptation to sea level rise, extreme climate events like tropical cyclones and associated storm surges, and coastal erosion control in the WTC NRM region.

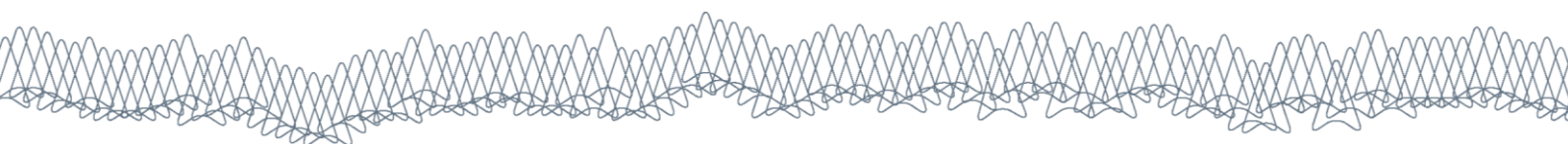
Mangroves move inland if the pace of sea level rise allows (Alongi 2008). It was found that mangroves nearby Key West, Florida have shifted inland by 1.5 km since the mid 1940s under a regime of sea level rise of 2.3-2.7mm/yr (Ross *et al.* 2000). In Western Australia it was found that mangroves are responding to coastal erosion and sea level rise by colonising landwards (Semeniuk 1994). If possible, mangroves in the WTC region are also likely to move landward in response to sea-level rise and coastal erosion. Facilitating this natural movement of mangroves would be a potential adaptation pathway for coastal protection in the WTC region, although many potential sites are currently used for agriculture and urban development. Mangrove movement may be facilitated through 'managed realignment', whereby coastal lands are deliberately reconnected with tidal systems by opening seawalls and filling drainage channels (Spalding *et al.* 2014). In many places across the world using this process of natural regeneration of mangroves has taken place and accretion processes have been re-established (Linham & Nicholls 2010; Luisetti *et al.* 2011). This method is being used increasingly in places where maintenance of artificial sea defence is expensive and risky (Spalding *et al.* 2014).

Littoral (coastal) forests provide a number of ecosystem services in the WTC Region (DEWHA 2009; Gallagher *et al.* 2010). They protect areas from erosion, filter sediments, nutrients and pollutants and reduce the impacts of flooding and storm surge events (Burgman *et al.* 2007; Murphy *et al.* 2012). They act as a buffer to coastal erosion and wind damage (Meier & Figgis 1985). They will also protect coastal communities, infrastructure such as roads, marinas, and agriculture and aquatic industries on floodplain areas of the WTC Region during tropical cyclones and associated storm surge, and in the face of ongoing sea level rise (Murphy *et al.* 2012; Chapters 4 & 5, this report). Severe tropical cyclones can cause major damage to littoral forests and

riparian vegetation reducing their capacity to provide essential ecosystem services. For example, heavy damage of littoral rainforest with melaleuca trees occurred north of Cardwell following Category 5 Severe Tropical Cyclone 'Yasi' (Murphy *et al.* 2012). Coastal erosion can lead to seawater intrusions into wetlands negatively impacting on biodiversity, tourism and recreation (Environment Planning 2011), and leading to the loss of public assets such as beaches and protective dune systems (Bustamante *et al.* 2012; Williams *et al.* 2012). Restoration of littoral forests may help protect remaining freshwater wetlands from seawater intrusions. Therefore protection and restoration of littoral forests will have profound positive impacts on coastal communities, terrestrial ecosystems and aquatic ecosystems in the face of climate change. Protection of littoral forests is potentially one of the least cost measures for the WTC Region.

Use of coastal plantations is a well-implemented concept across the world for coastal protection and erosion control with 375,000 ha of coastal plantations having been established across the world, mainly for coastal protection (Spalding *et al.* 2010). Therefore coastal plantations comprising robust native tree species will build resilience to anticipated increases in tropical cyclone winds and ocean storm surge threats in the WTC Region. As the primary target is coastal protection and erosion control rather than production, larger plantation widths with closer tree spacing using cyclone-resistant tree species would be desirable.

Hybrid engineering is the combination of hard engineering and green engineering applications to mitigate river and coastal erosion threats (Spalding *et al.* 2014). Green engineering may not be sufficient in some areas to ensure coastal protection and hard engineering solutions may not be acceptable due to the economic and, social costs (Spalding *et al.* 2014) or biodiversity impacts. However, in some parts of the WTC NRM Region, hybrid-engineering solutions may be an adaptation pathway to provide rapid and effective protection for coastal communities and adjacent agricultural, urban and sensitive protected areas. For example the revegetation of hard engineering sites on riparian zones in the WTC Region.



Beaches, dunes and barrier islands built of sand are sediment reserves and subsequently an important component of adaptation pathways in the face of sea level rise and storm surge threats (Defeo *et al.* 2009). Dunes have significant positive impacts on reducing wave and storm surge thereby protecting coastal communities and reducing erosion during extreme events like tropical cyclones (Ba Thuy *et al.* 2009). It is necessary to ensure vegetation presence for the effective structure and stability both of dunes and barrier islands (Bhalla 2007; Feagin *et al.* 2010). Coastal protection functions of dunes and barrier islands are reduced by vegetation removal or introduction of exotic species (Bhalla 2007; Feagin *et al.* 2010), and by hard structures/coastal development that are interfering with natural coastal processes, erosion and deposition patterns.

Carbon sequestration

There is high potential for more carbon sequestration and storage through improved management practices, environmental planting, mixed farming and land rehabilitation.

Native species with relatively high wood density and slow growth rates are more likely to store carbon for a long time.

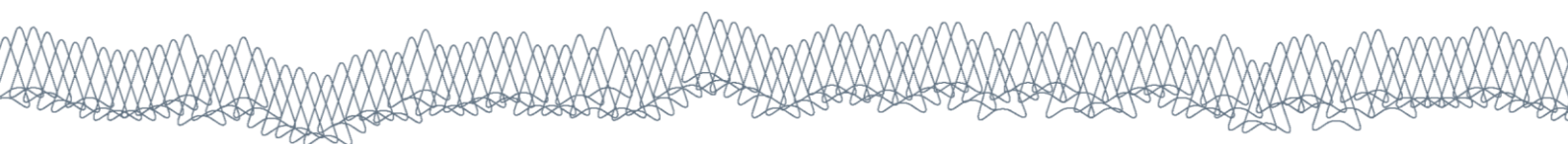
There should be consideration of potential limitations to C sequestration on rangelands.

Australia's soils and forests store large quantities of carbon; however they also emit a large quantity of carbon due to land use change, e.g. savanna burning due to both naturally caused wildfires and planned burning for pasture management (Battaglia 2011). Agroforestry is a potential adaptation option for generating multiple benefits such as carbon sequestration, watershed management and biodiversity restoration (George *et al.* 2012). Landscape rehabilitation and mixed farming - including integrating trees with farming - are likely to improve soil health, and increase carbon sequestration and storage (Battaglia 2011). Among the different planting options environmental plantings have the highest potentiality to sequester and store carbon (George *et al.* 2012). The

WTC Region has the potential to increase carbon sequestration and storage in both plants and soils by forest restoration and mixed farming. Ongoing environmental plantings need to be enhanced and implemented at the landscape scale.

A study of replanted trees (Curran *et al.* 2008) found that those species with high wood density had been less damaged by cyclonic winds during cyclone 'Larry'. Higher wood density, long-lived large trees with extensive root systems are more useful to store carbon in the long term (Murphy *et al.* 2012). Scattered trees will also reduce the risk of carbon release by fire, pests and tropical cyclones, together with their secondary positive impacts on water supply (Battaglia 2011).

Rangelands emit carbon to the atmosphere mainly from three different sources- land use change and management, livestock and savanna burning (Cook *et al.* 2010). In tropical savannas fuel decomposition rates are high and equilibrium fuel loads are reached within 3-5 years (Cook *et al.* 2010; Cook 2003), therefore reducing fire frequency likely to reduce carbon emission to the atmosphere (Cook *et al.* 2010). Improved grazing management is essentially an important pathway to adapt with climate change. For improved grazing potential options could be managing shelterbelts, improving grass, time control rotational grazing and avoiding over stocking. Improved grazing will enhance carbon sequestration potentials of rangelands and will reduce carbon emissions. It will also provide other co-benefits, such as biodiversity conservation. A substantial amount of carbon is stored up to 1 m depth in the soil of rangeland and savanna soils (Baker *et al.* 2000). Harms and Dalal (2003) have reported a 7.9% decline of soil carbon stock to a depth of 0.3m after clearing of *Acacia* and *Eucalyptus* woodlands and savannas for cattle grazing in Queensland, which is nearly 260 Mt CO₂-e (National Land and Water Resources Audit 2001). A study in Bundaberg (Schulke undated) has found that thinning may increase grass production only in the short term. Woodland clearing for grazing is detrimental for the environment and in most of the cases not economically viable (Cook *et al.* 2010). Therefore, in the WTC Region, lands that are now managed for grazing could be significantly improved with better grazing management.



Habitat provision for biodiversity

Integrated farm management has potential benefits for biodiversity as well as farm productivity.

Ongoing and enhanced invasive species management is required.

Integrating trees into farming landscapes and strategically retaining strips of regrowth in pastoral landscapes, are both likely to have little impact on farm productivity (Battaglia 2011); if applied correctly the impact on farm productivity will be positive. These trees can provide habitat for wildlife (including 'stepping stones' to enable movement) and shelter from extreme climate events such as heat waves, floods, storm surges and tropical cyclones. These trees will also have an influence on microclimate at the local scale, thereby reducing local air temperatures. These trees can help to increase the soil fertility; more importantly nitrogen, enhanced nutrient cycling, reduced stressed on livestock, soil health (which brings in the often neglected component of microbial biodiversity). These trees are also vital in the cycling of Molybdenum a key limiting factor in Azitobacter and nitrogen fixation (G. Kay 2014, personal communication).

Some invasive species may benefit from changing temperature and rainfall patterns, as well as increased atmospheric CO₂ (Dukes & Mooney 1999; Chapter 2, this report). Invasive plants may also inhibit natural regeneration and colonisation of native species (Murphy *et al.* 2012). Disturbances also create more favourable conditions for plant invasions (Laurance 1991, 1997). Large-scale disturbances like tropical cyclones which are predicted to increase in intensity in the WTC Region (Turton 2014) may promote the recruitment and spread of invasive species (Murphy *et al.* 2012) over native taxa. These processes will likely interact with other disturbances. For example, after Tropical Cyclone 'Larry' in the Babinda-Tully area, it was found that woody weeds grew more quickly, showed low mortality rates and persisted over a longer time frame in the fragmented landscapes compared with intact forest areas (Murphy *et al.* 2008a, Murphy *et al.* 2010; Murphy *et al.* 2008b, Turton 2008).

Timber provision

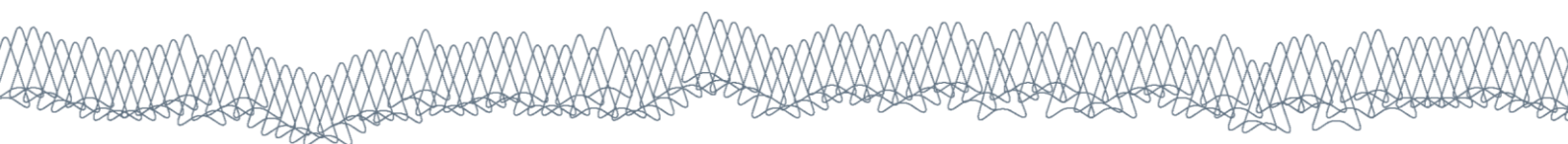
More emphasis on cyclone-resistant tree species is required.

Forest management practices may build climate change resilience.

Opportunities to increase growth rates due to elevated CO₂ should be taken advantage of where practical.

Australian native conifers (hoop/Kauri pine) are more likely to be resistant to tropical cyclones than exotic pine species (Timber Queensland 2012). A study after Cyclone 'Larry' found that *Backhousia bancroftii* (Johnstone River Hardwood/ Langdon's Hardwood) was more resistant to cyclonic winds than many other tree species in the WTC Region (Metcalfe *et al.* 2008). This tree grows in a wide range of altitudes from sea level to 700m (Australian Tropical Rainforests Plants). Tree resistance to cyclones is influenced by seed provenance and seeds sourced from regions that have evolved in environments where cyclones occur frequently are likely to more resistant to strong wind events. In the areas affected by Cyclone 'Yasi' in 2011 it was found that the Cuban-sourced exotic pine (*Pinus caribaea*) - which is regularly subjected to strong coastal winds - was less affected than mountain Honduras-sourced exotic pine of the same species (Timber Queensland 2012).

Some forest management practices may build forest plantation resilience to climate change. For example mixed-species plantings can minimise impacts from pest outbreaks, and wide-spacing of trees may minimise impacts from forest fires (Dale *et al.* 2001; Joyce *et al.* 2008), and prescribed burning by reducing fuel loads (Spittlehouse & Stewart 2003; Scott *et al.* 2008). In the WTC Region, appropriate prescribed burning regimes and mixed plantings are potentially important adaptation pathways under climate change.



Traditional values

Incorporating local and Indigenous knowledge in formal decision-making about ecosystem services and climate change adaptation is important.

Enhancing Indigenous adaptation options and community-based adaptation is useful.

Strong linkages between local knowledge and formal science are required.

Scientists have found that local communities' knowledge is useful in climate change science and policy (Chaudhary & Bawa 2011; Chapter 6, this report). Indigenous adaptation options are usually based on long-term practice, experience and observation of communities. If there is an Indigenous adaptation option in place then government and other organisations should assist to increase their adaptive capacity, e.g., by providing training, and financial incentives to facilitate a continuous flow of ecosystem services in landscapes. Community-based adaptation is a popular concept, especially in developing countries and places where communities are dependent on forest resources. This approach is also applicable to areas in the WTC Region, especially remote areas such as Cape York (details in Chapter 6, this report). Working with Indigenous groups to manage places of particular cultural significance may be an important adaptation option in the face of climate change.

Strong linkages between local knowledge and formal science are required for successful adaptation strategies. Climate change is a long-term phenomenon and decision-making is problematic, as various uncertainties exist. Adaptation should also be placed before the more serious negative impacts take hold. Indigenous knowledge may help to identify the impacts and also to identify the areas where immediate action is needed to build resilience to climate change. Scientists have found similarities between Indigenous knowledge-based identification of climate change impacts and traditional science based identification of impacts (Chaudhary & Bawa 2011).

Marine ecosystem services

Maintaining continuous native vegetation cover in terrestrial ecosystems will reduce some stressors on the Reef and will increase its resilience to climate change.

Marine ecosystems are already under threat from climate change (Chapter 2, this report). The Great Barrier Reef's health and hence resilience are negatively impacted by terrestrial sediment runoff (Bustamante *et al.* 2012). Other stresses like nutrients and pesticides from agricultural lands, land clearing and other land uses increase the vulnerability of marine ecosystems. Sediments and nutrients load in the Great Barrier Reef due to extensive clearing of low land vegetation for agriculture, ground cover disturbances, and agricultural practices have already been reported (Murphy *et al.* 2012). So managing terrestrial catchment vegetation cover to minimise runoff is an important adaptation pathway which will increase the reef's resilience to climate change and other stressors, such as coral bleaching and rising acidity (Bustamante *et al.* 2012).

Barriers of current mechanisms for adapting to climate change

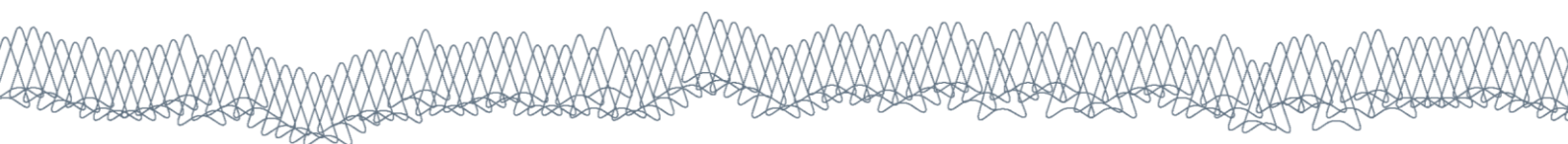
Lack of sufficient funding is an ongoing concern.

Frequent government policy shifts are not helpful.

Complexity of methods and approaches is discouraging for many stakeholders.

Uptake of adaptation measures depend on attitudes beliefs and perceptions about climate change by members of the society and their level of exposure to mass media.

Current government funding for carbon offset schemes is insufficient and the gains in protection will be outweighed by the rapid loss of biodiversity and ecosystem services. Funding cuts to regional



organisations presents a great challenge to promoting adaptation mechanisms since as a result - for example - some organisations may have to reduce staff members who closely work with stakeholders in this area (van Oosterzee *et al.* 2013). One of the main barriers for current adaptation mechanisms is that regulations are often applied to promote adaptation actions but little importance is given to the fact that these regulations do not always provide enough funding to engage stakeholders in these enterprises - which in turn - has the effect of discouraging people from adopting adaptation mechanisms (van de Koppel & Reitkerk 2000).

Policy shifts are argued to be an important barrier to climate adoption since uncertainty in the direction of policies generally tends to discourage stakeholders from adopting new methodologies. In Australia there have been various shifts in policies such as the Carbon Farming Initiative (CFI), where the complex nature of the scheme discourages landholders from dealing with climate change adaptation and mitigation (van Oosterzee 2012). Current financial mechanisms of carbon offsets, such as the CFI are complex and require high financial investment for project establishment and registration (van Oosterzee 2012). Therefore non-adoption of this type of initiatives by small landholders emerges as another barrier.

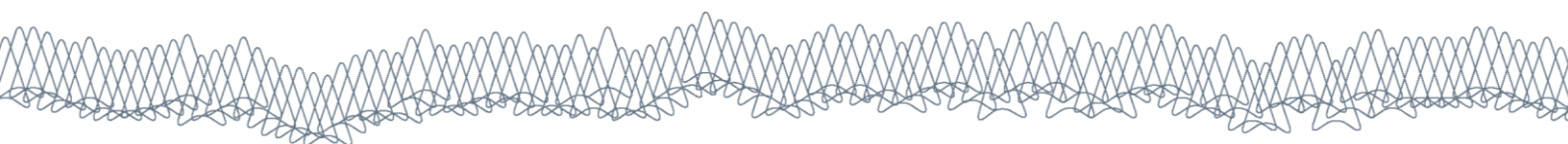
Uptake of mechanisms for climate change adaptation depends on attitudes and perceptions of the general public. Akter and Bennett (2011), in a study carried out to households in New South Wales, Australia found that: (1) "willingness to pay for climate change mitigation is significantly influenced by their beliefs of future temperature rise", (2) "perceptions of policy failure have a significant negative impact on respondents' support for the proposed mitigation measure" (3) "preferences for the proposed policy are influenced by the possibility of reaching a global agreement on emissions reduction" and (4) "willingness to take action against climate change, both at the national and household level, is found to be influenced by their level of mass-media exposure".

Mechanisms for establishing payments for ecosystem services

An appropriate process is required for payment for ecosystem services.

There is the need to develop appropriate mechanisms to pay for ecosystem services given that they are vital for human wellbeing, are becoming increasingly limited and that many of the key services do not have substitutes (Farley & Costanza 2010). Payment for ecosystem services (PES) is a policy instrument that aims to combine 'market forces' and 'environmental protection'. Wunder (2005) provided the widely accepted definition of PES as a "voluntary transaction where a well-defined ecosystem service (or a land-use likely to secure that service) is being bought by a (minimum one) ecosystem services buyer from a (minimum one) ecosystem service provider if and only if the ecosystem service provider secures ES provision (conditionality)". PES is structurally similar to other 'incentive-based policies' and the objective of this mechanism is to reward individual landholders and communities to foster the adoption of activities that enhance the continued provision of ecosystem services (Jack *et al.* 2008). The central idea of a PES is to encourage 'external beneficiaries' of ecosystem services to financially support - under defined contractual conditions - 'local landholders' in order to adopt sustainable practices, thereby securing the continued provision of the services (Wunder 2005). PES may also be of different types (Table 3.1).

The PES mechanism has developed rapidly during the last decade and has gained international attention (Perrot-Maitre 2006; Bulte *et al.* 2008). Payments from environmental services have been applied even before the term was introduced such as the case of Vittel's private scheme developed and implemented in France, in order to protect the aquifer that provides the mineral water for the company (Perrot-Maitre 2006). Numerous PES mechanisms have been implemented or are under implementation, both in developed and developing countries. Some PESs are private initiatives, others are



run by national and international NGOs or other organisations and there are also governmental administered schemes. One common characteristic of

PES schemes is that they are voluntary. Some examples have been compiled in Table 3.2.

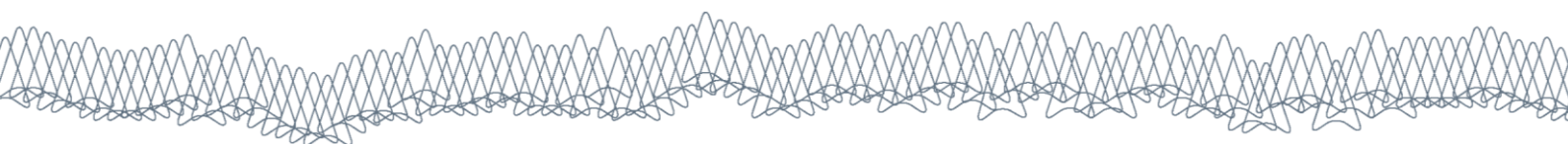


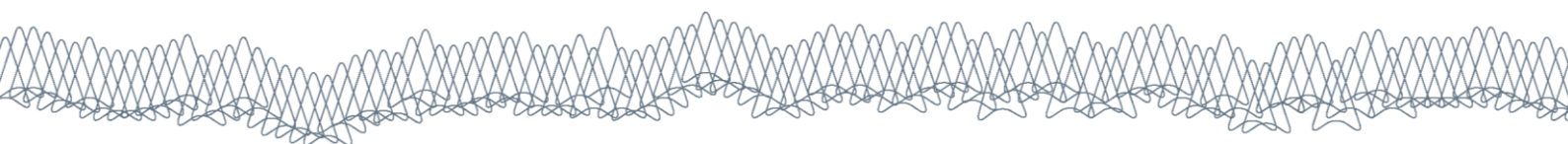
Table 3.1 Types of Payments for Ecosystem Services

SCHEME TYPES	SCHEME DETAILS
Area- vs. product-based schemes	The most common type is <i>area-based schemes</i> , where contracts stipulate land- and/or resource-use caps for a pre-agreed number of land units. <i>Product-based schemes</i> is the second most common type of PES, where consumers pay a ‘green premium’ on top of the market price for a production scheme that is certified to be environmentally friendly, especially vis-à-vis biodiversity (as cited in Pagiola & Ruthenberg 2002).
Public vs. private schemes	In <i>public schemes</i> the state acts on behalf of ES buyers by collecting taxes and grants and paying alleged ES providers. <i>Private schemes</i> are more locally focused and buyers pay directly. Public schemes are generally larger in scope and have the state providing legitimacy, which many private schemes struggle hard for. On the downside, public schemes can become overloaded with side objectives catering to voters rather than supplying ecological services proper, they are less flexible vis-à-vis targeting of strategic ES sellers, and they tend to be less efficient in securing additional ES provision.
Use-restricting vs. asset-building schemes	<i>Use-restricting PES schemes</i> reward providers for conservation (including natural regeneration) for capping resource extraction and land development; or for fully setting aside areas, such as for protected habitat. Here, landowners are paid for their conservation-opportunity costs, plus possibly for active protection efforts against external threats (as cited in Hardner & Rice 2002). <i>Asset-building schemes</i> PES aim to restore an area’s ES, for example (re)planting trees in a treeless, degraded landscape. Conservation-opportunity and protection costs aside, PES may here also compensate the direct costs of establishing ES, often through investments within agricultural systems (as cited in Pagiola et al. 2004)

Source: Wunder (2005)

Table 3.2 Examples of PES schemes around the world

PES SCHEME	SHORT DESCRIPTION	COUNTRY
Vittel (Perrot-Maitre 2006)	Vittel mineral water company is providing incentives to farmers to change farming practices and technology in order to protect the aquifer to ensure water quality (reducing the risk of nitrate contamination from agricultural activities). The negotiations between the local landholders and the owners of Vittel started in 1988.	France
Conservation Reserve Program (CRP) (Farm Service Agency 2013)	The CRP is voluntary program, administered by the Farm Service Agency (FSA), which support farmers to protect “environmentally sensitive land” and enhance conservation outputs. The ES targeted are improvement of water quality, avoiding soil erosion and conserving and enhancing wildlife habitat.	USA
Proambiente Brazil (Hall 2008)	Reduction or avoidance of deforestation, carbon sequestration, recuperation of ecosystem hydrological functions, soil conservation, preservation of biodiversity and reduction of forest fire risks. The PES scheme was adopted by the Federal Government in 2003.	Brazil
The Carbon Farming Initiative (Department of Climate Change and Energy Efficiency 2012)	The Carbon Farming Initiative is a voluntary scheme that provides landholders with the opportunity to access carbon markets, presenting them with an alternative way to generate income through the adoption of activities that either sequester carbon dioxide or CO ₂ equivalents (CO ₂ -e) from the atmosphere or reduce greenhouse gas (GHG) emissions are considered to earn carbon credits which can be later sold to businesses to offset their emissions. The CFI Act was passed in 2011.	Australia



PES SCHEME	SHORT DESCRIPTION	COUNTRY
Los Negros Valley (Asquith <i>et al.</i> 2008)	In this case the USFWS pays for the protection of the habitat for migratory birds and the Municipality of Pampagrande pays for the provision of water for irrigation during dry season, services provided by the same “upland forest and puna (native central Andean alpine grassland) vegetation”. Fundacion Natura Bolivia started PES negotiation in 2003.	Bolivia
Regional Integrated Silvopastoral Ecosystem Management Project (Pagiola <i>et al.</i> 2005)	This program was carried out from 2002 to 2008. The objectives were to demonstrate and measure a) the effects the introduction of payment incentives for environmental services to farmers to adopt integrated silvopastoral farming systems in degraded pasture lands, and b) the improvements resulting for ecosystems functioning, global environmental benefits, and local socio-economic benefits obtained through the provision of ES.	Colombia, Costa Rica and Nicaragua
Fostering Payments for Environmental Services in the Danube Basin (WWF 2012)	This PES scheme promotes the maintenance, improving or adoption of conservation friendly land uses in the Lower Danube and Danube delta. Preparations for the PES project started in 2002.	Bulgaria, Moldova, Romania and Ukraine

Waage *et al.* (2008) propose a four-step approach to develop Payments for Environmental Services that are presented in Figure 3.2. As a result of the analysis of information of a workshop held in Costa Rica, Farley and Costanza (2010) recommended measuring, bundling, scale-matching, property rights, distribution issues, sustainable funding, adaptive management, education and politics and participation and policy coherence as principles (Table 3.3) to be considered for payments for ecosystem services.

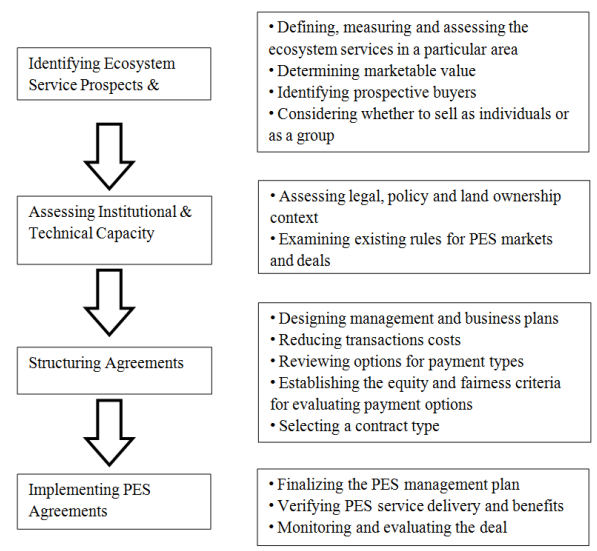


Figure 3.2 A Step-by-Step Approach to Developing PES Deals

Source: Waage *et al.* (2008).

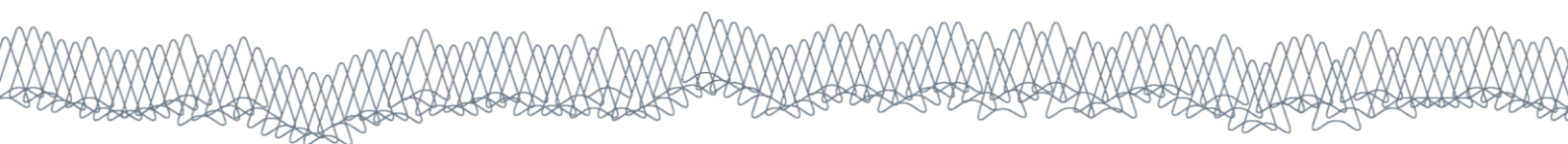
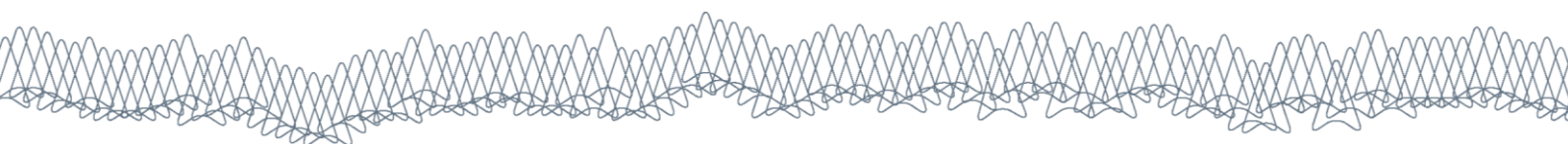


Table 3.3 Principles concerning the use of PES systems

PRINCIPLES	DETAILS
Measuring	We need to continue to develop better methods to measure, map, model, and value ecosystem services at multiple scales. At the same time, we cannot wait for certainty and precision to act. We must synergistically continue the process of improvement of measurements with evolving institutions that can effectively utilise these measurements.
Bundling	Most ecosystem services are produced as joint products (or bundles) from intact ecosystems. The relative rates of production of each service varies from system to system and site to site, and time to time, but we must consider the full range of services and the characteristics of their bundling in order to prevent creating perverse incentives and to maximise the benefits to society.
Scale-matching	The spatial and temporal scale of the institutions to manage ecosystem services must be matched with the scales of the services themselves. Mutually reinforcing institutions at local, regional and global scales over short, medium and long time scales will be required. Institutions should be designed to ensure the flow of information between scales, to take ownership regimes, cultures, and actors into account, and to fully internalise costs and benefits.
Property rights	Establishing appropriate property rights regimes is essential for implementing PES systems. However, given the public goods nature of most ecosystem services, we can either use existing private property rights, change property rights, or develop systems that can privatise ecosystems and their services without privatising them. For example, common property asset trusts are one way to effectively do this.
Distribution issues	The distribution of costs and benefits from PES systems need to be carefully considered. Systems should be designed to ensure inclusion of the poor, since they are more dependent on common property assets like ecosystem services. In particular, wealthier nations should be prevented from free-riding, and instead pay for the services they receive from the biodiverse and ecologically productive ecosystems in less developed countries.
Sustainable funding	PES systems should link beneficiaries with producers. In order to be sustainable, fees should be collected from beneficiaries in order to pay producers to continue to provide the services — either by paying private land owners or through investments in commonly owned natural capital assets.
Adaptive management	Given that significant levels of uncertainty always exist in ecosystem service measurement, monitoring, valuation, and management, we should continuously gather and integrate appropriate information with the goal of learning and adaptive improvement. To do this we should evaluate the impacts of existing PES systems and design new systems as experiments from which we can more effectively quantify performance and learn.
Education and politics	Two key limiting factors in implementing PES systems are shared knowledge of how the systems work and political will. Both of these can be overcome with targeted educational campaigns, clear dissemination of success and failures directed at both the general public and elected officials.
Participation	All stakeholders (local, regional, and global) should be engaged in the formulation and implementation of PES systems. Full stakeholder awareness and participation contributes to credible, accepted rules that identify and assign the corresponding responsibilities appropriately, and that can be effectively enforced.
Policy coherence	PES systems will be most effective when they form part of a coherent set of policies to address ecosystem use and management. They are less likely to work when other policy instruments are providing opposing incentives (for example by subsidising the use of water, energy etc.) or when legislation controlling allocation is inflexible

Source: Farley & Constanza (2010)



What if carbon is priced much lower?

Even though the current carbon price seems to be relatively high, it may not be profitable for small landholders to implement carbon abatement projects.

The repeal of the Carbon Pricing Mechanism and the establishment of the Direct Action Plan and the Emission Reduction Plan announced by the current government may have a significant impact on the carbon price.

Volatility of carbon prices in the European Union Emissions Trading Scheme could have a huge impact in the Australian carbon market due to the proposed future linking of the markets.

Uncertainty around future carbon prices reduces the willingness of stakeholders to make long-term commitments.

Effective communication to stakeholders about additional benefits of carbon sequestration activities is needed to counteract an eventual carbon price drop.

There is the need to continue analysing the applicability of Carbon Capture and Storage which being tested in Australia as well as internationally.

The future impact of Carbon Capture and Storage on carbon prices is unclear.

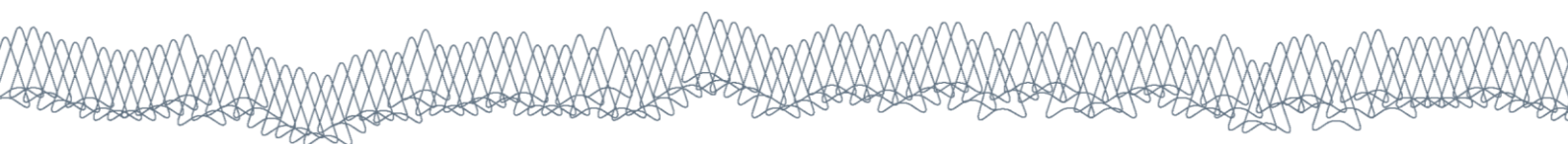
There is not clear evidence in the literature about the environmental consequences of a significantly lower price of carbon. Nevertheless, as carbon sequestration and emission-avoidance projects involve high establishment costs, they are highly dependent on carbon markets and prices. In Australia, in a study carried out mostly large in properties, “several thousand hectares in area”, a company estimated that the costs, associated with registering and auditing environmental planting projects are around 20,000 per property. Despite the expectation of lower costs for smaller properties, the “fixed costs related to the

preliminary assessment and project management will be the same regardless of project size” (Knudsen & Putland, 2012).

Correspondingly, van Oosterzee (2012) states that the returns will not cover the costs resulting from registering the rights to the carbon and other expenses such as survey, plan preparation or forest establishment costs which contradicts “the expectation that forests deliver low-cost abatement”. With carbon prices ranging from \$23 a tonne in 2012 to \$25.40 in 2015 (Australian Government, 2013a; Commonwealth of Australia, 2012), the expected income ranges from \$160 to 345 ha/year (Knudsen & Putland, 2012). This implies that these types of plantations would only be profitable for large-scale farms. Consequently, it can be assumed that a low price of carbon in national and international markets could provoke discouragement for stakeholders to setup new GHG-abatement projects.

The European Union Emission Trading Scheme (EU ETS) is the biggest carbon market in the world, operating in the 28 EU members and three associated member states belonging to the European Economic Area (EEA) and the European free trade Association (EFTA) (European Commission 2014a). The EU ETS set prices for carbon emission of about 11,500 high-energy consuming industries, covering the 46% of European emissions, since 2005 (Alberola *et al.* 2008). The EU ETS and the Australian carbon markets are setting “the first full inter-continental linking of emission trading systems”. This “full two-way link” market will start around July 2018. In the meantime, from July 2015 an “interim link” will allow Australian businesses to offset their emissions using EU ETS allowances (Australian Government 2013b; European Commission 2014b). Although, the plan to link the European and Australian carbon markets was announced in 2012 (Australian Government 2013b; European Commission 2014b), uncertainty for this to happen persists.

Fluctuations of carbon markets/prices can have important impacts on carbon abatement projects. In a study conducted on the UE ETS, Feng *et al.* (2011) state that “the carbon market is a complex volatility model” as prices can be affected by different factors such as power prices, weather and traders’ behaviour. In the same context the Parliament of Australia (2012)



conveys that the fluctuation of carbon prices in the EU ETS (Figure 3.3) are driven by different market factors such as offer and demand, but also economic, financial and environmental factors including: industrial production, financial markets, energy prices and weather as well as policy issues and uncertainty of policy shifts.

In Australia, since the start of the Carbon Pricing Mechanism (CPM), July 2012, the price per ton of CO₂-e, for the fixed price, was set at AU\$ 23 in 2012–13, \$24.15 in 2013–14, and \$25.40 for 2014–15. In 2015, from the flexible period, the price will be set by the market (Australian Government, 2013a; Commonwealth of Australia, 2012). According to Commonwealth of Australia (2012), during the flexible period, 2015 to 2018, a price floor AU\$ 15, and a price ceiling, AU\$ 20 higher than the expected international price, were to be set. However the Australian carbon market is experiencing critical changes. On one hand, the repeal of the CPM, which will “abolish the carbon tax from 1 July 2014” and the establishment of the

Direct Action Plan and Emission Reduction Plan has been announced by the current government (Australian Government 2014). Furthermore, there will not be a floor price per ton of CO₂-e due to the linking with the EU ETS (Mansell & Sopher 2014), which could have an impact on the price of carbon adding more uncertainty to the carbon market.

It is necessary to share information effectively with stakeholders about the benefits resulting from the adoption of carbon sequestration activities, which could be crucial to counteract negative impact of an eventual drop of carbon prices. Mechanisms to pay for carbon sequestration are justified because the adoption of new farming activities may present some risk to farmers. Nevertheless, there are additional important economic and environmental benefits (Table 3.4) resulting from the adoption of “conservation agricultural systems” (FAO and CTIC 2008).

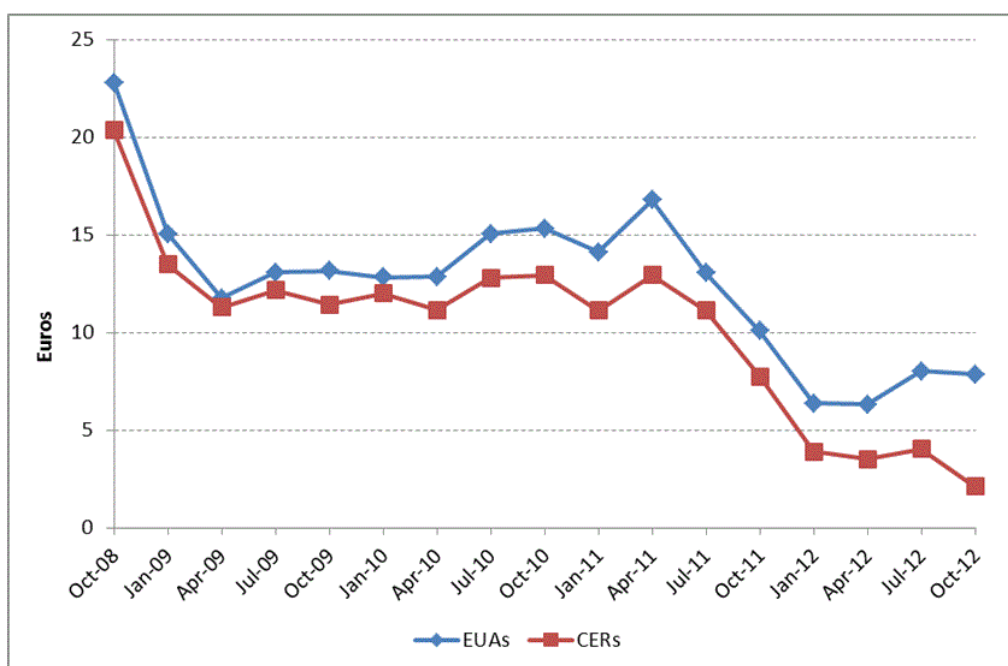
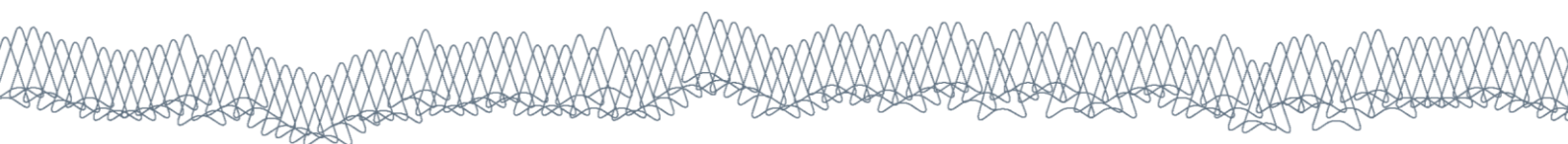


Figure 3.3 Prices of Carbon in EU ETS 2008-2012

Source: Parliament of Australia (2012).



Carbon capture and storage (CCS) also called geological sequestration or geosequestration that refers to the process of capturing carbon dioxide emitted from burning fossil fuels, which then is compressed, transported to an adequate geological formation that will be used as storage and then injected (CO2CRC 2011; Metz *et al.* 2005). Carbon capture and storage is not a new or untested technology, oil and gas industries have been using it for around forty years to improve recovery of oil and gas (New South Wales Trade and Investment 2014). CCS can be applied to industries that produce large amounts of carbon dioxide, production of natural gas, synthetic fuel production, etc. (Metz *et al.* 2005). Various demonstration projects in execution or

planned in Australia, including 3 in Queensland (CO2CRC 2011) : CarbonNet Project, Victoria (CCS Flagship Project), South West Hub Project, Western Australia (CCS Flagship Project), Surat Basin Integrated CCS Project, Queensland, Callide Oxyfuel Project, Queensland, CO₂CRC Otway Project, Victoria, The Gorgon Project, Western Australia, GDF SUEZ Australian Energy Carbon Capture Plant, Victoria, AGL Loy Yang Project, Victoria, CO₂CRC UNO Mk 3 Project, Vales Point Power Station, New South Wales, CSIRO Vales Point PCC Project, CO₂CRC Membrane CO₂ Capture Facility, Tarong PCC Project, Queensland, NSW CO₂ Storage Assessment Program.

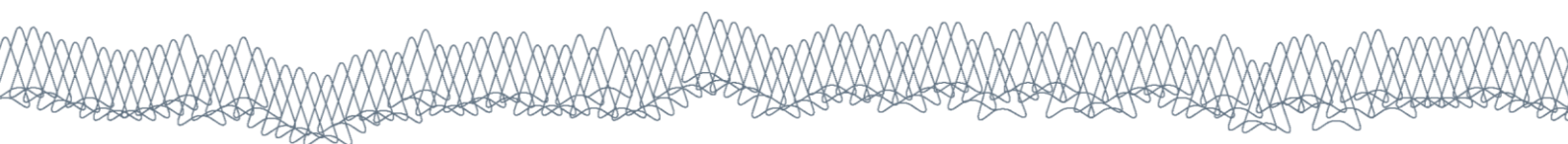
In a report about costs of CCS in EU, Zero Emissions

Platform (2011) states that “Post 2020, CCS will be cost-

Table 3.4 Key environmental and economic services that can be derived from conservation agricultural systems.

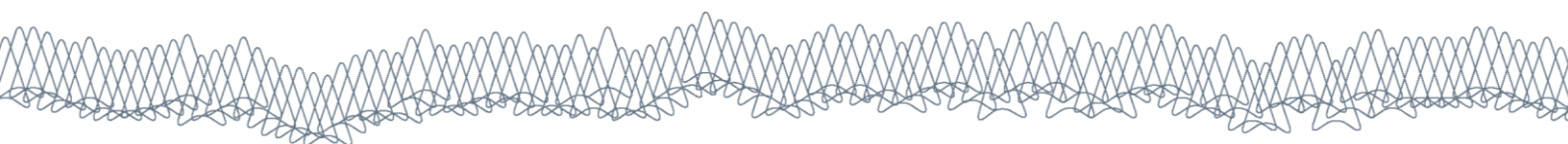
FINANCIAL BENEFITS FOR FARMERS	BENEFITS TO COMMUNITIES & SOCIETY	ENVIRONMENTAL BENEFITS
Greater yields and improved yield stability invariable weather	More reliable and cleaner water supplies resulting in lower treatment costs	Favourable hydrologic balance and flows in rivers to withstand extreme weather events
Reduced fuel and labour requirements	Less flooding due to better water retention and slower runoff, resulting in less damage to roads, canals, ports and bridges	Reduced incidence and intensity of desertification
Greater resilience to drought through better water infiltration and retention	Improved air quality with less wind erosion	Increased soil biodiversity
Alleviation of labour demand at key times in the year, permitting diversification into new on-farm and off-farm enterprises	More secure food and water sources	Less soil erosion resulting in less sediment in rivers and dams
Better cycling of nutrients and avoiding nutrient losses	Economic and industrial development opportunities	Potential for reduced emissions of other greenhouse gases, including methane and nitrous oxide, if compaction is avoided
Higher profit margin with greater input-use efficiency	Improved quality of life	Reduced deforestation due to land intensification and more reliable and higher crop yield
Increasing land value due to progressive improvements in environmental quality		Less water pollution from pesticides and applied fertiliser nutrients
		Less hypoxia of coastal ecosystems

Source: FAO and CTCI 2008



competitive with other low-carbon energy technologies” and that CCS is already being considered as a crucial option to fight climate change “within a portfolio of technologies”. However, the department of Trade and Investment of New South Wales claims that internationally CCS is still being demonstrated to gain understanding and reduce costs and that commercial

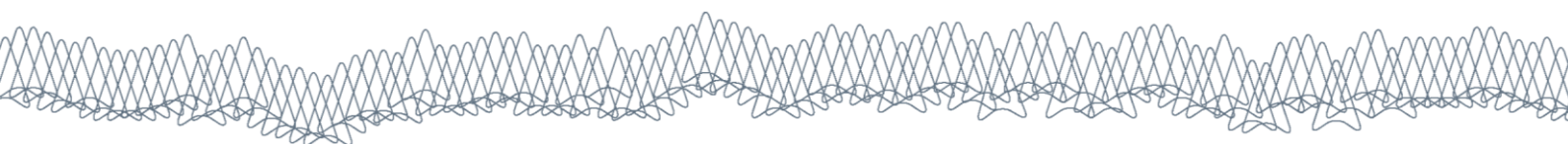
applications of this technology are not possible yet (New South Wales Trade and Investment 2014). There is the need to continue with the analysis of this mitigation option and the possibilities for application within the region. Since CCS is still in trial stages, the future impact of CCS on carbon prices is unclear.



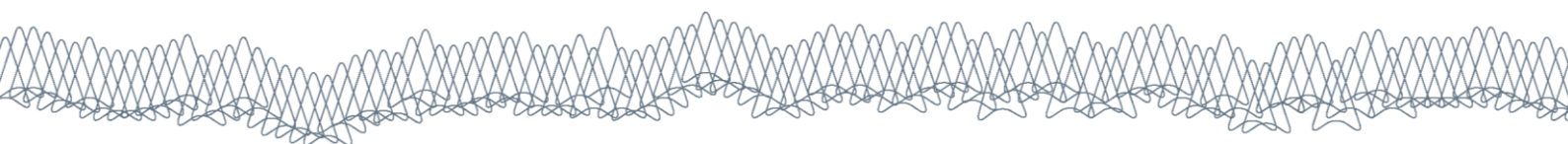
Summary of adaptation options for ecosystem services

Table 3.5 Major climate change impacts and potential adaptation options for ecosystem services. Adaptation options that also potentially mitigate greenhouse gas emissions are marked **(M)**.

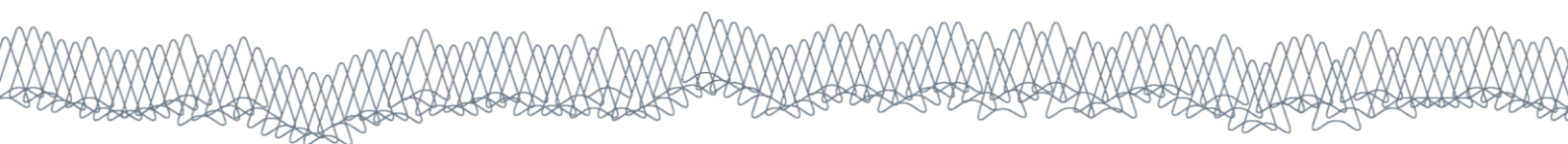
EXAMPLE ADAPTATION OPTIONS				
Climate change	Major impacts	Protect	Accommodate	Retreat
Increased atmospheric CO ₂	1. Exacerbate all climate change impacts	<ul style="list-style-type: none"> · Sequester more carbon through environmental plantings using longer-lived species with higher wood density and extensive root systems (M); · Limit clearing of woodlands and savannas to protect soil carbon stocks (M); · Integrate trees with farming practices (M); · Reduce fire frequency in savanna systems (M); · Manage shelterbelts, improve grasses, implement rotational grazing and manage stocking rates (M); · Improve carbon capture and storage technologies (M). 		
Increased temperatures	1. Increased water temperatures		<ul style="list-style-type: none"> · Maintain and restore riparian vegetation to create cool water refugia (M) 	
	2. Impacts on farm productivity (e.g., livestock health)		<ul style="list-style-type: none"> · Integrate trees into farm landscapes, including regrowth. 	
Sea level rise	1. Increased vulnerability of		<ul style="list-style-type: none"> · Conserve landward 	



EXAMPLE ADAPTATION OPTIONS				
	coastal communities due to inundation of mangrove systems		sea level rise refugia for coastal vegetation systems; · Facilitate landward migration of mangroves.	
	2. Sea water intrusion into freshwater wetlands		Conserve and restore littoral forests (M)	
Extreme events (increased occurrence of high intensity cyclones, extreme rainfall events, heatwaves)	1. Increased vulnerability of coastal communities during cyclones, especially in combination with sea level rise and storm surge.	Hybrid engineering defensive measures. (e.g., revegetation of hard engineering sites in riparian zones).	· Protect & restore mangroves, littoral forests and vegetation on dunes and barrier islands (M) ; · Establish protective coastal tree plantations using robust species (M) · Managed realignment to promote natural regeneration of mangroves by reconnecting coastal areas with tidal systems.	
	2. Reduced water quality due to sediment and pollutant runoff into waterways during heavy rainfall events		Maintain or restore ground cover and woody riparian vegetation to slow overland flow and reduce soil erosion.	
	3. Flooding and erosion during heavy rainfall events		· Restoration of vegetation on floodplains (M) ; · Off-channel basins and wetlands to store water; · Channel reconfiguration; · Bank stabilisation.	
	4. Damage to the Great Barrier Reef system		Conserve and restore native vegetation cover in reef catchment area (M)	



EXAMPLE ADAPTATION OPTIONS				
	5. Damage to agroforestry		<ul style="list-style-type: none">· Select more resistant species. Source seed from areas subject to cyclones;· Use mixed-species plantations to increase resilience e.g., to pest outbreaks.	
More variable rainfall	1. Reduced availability of freshwater		<ul style="list-style-type: none">· Water sensitive design at micro- and macro-scales;· Groundwater extraction;· Water savings measures, esp. during the dry season.	



Barriers to potential adaptation options

Scepticism and misinformation about climate change science are an ongoing issue

There are uncertainties about the magnitude of climate change effects.

Linkages among policy-makers, researchers and landholders need to be improved.

Well-developed evaluation tools for assessing adaptation options are a priority.

There is a strong mindset that all climate adaptation options are expensive.

In Australia ongoing scepticism is a barrier for adaptation to climate change (Hennessy 2007). Scepticism is a real problem for climate change adaptation because it influences the attitude of different stakeholders to not act to deal with anticipated costs and benefits of climate change. Inadequate information flow about climate change is also a barrier to adaptation (Rodriguez *et al.* 2009).

Climate change is a very long-term phenomenon and it is also very difficult to precisely predict what the future may be. Although there is a strong consensus about the climate change impacts on different ecosystem services like water provision, carbon sequestration, agricultural production and habitat provision, uncertainty exists about the level of magnitude, which also discourages the community to act to adapt with climate change in the short term. Uncertainty in climate change projections – particularly rainfall - is a barrier to climate change adaptations in Australia (Hennessy 2007).

In Australia climate change related policy and regulations always varies with changes in government at all levels, despite the fact that long-term commitment is required from the NRM adopters to receive any incentives from governments.

The linkage among various strata of government - from national to local - regarding climate adaptation policy,

plans and requirements is weak in Australia (Hennessy 2007), which hinders or delays the adaptation options in the NRM sector. Potential adopters are rarely interested to adopt something if they know little or nothing about it (Rodriguez *et al.* 2009). Lack of on-farm trials and demonstrations, and lack of sufficient institutional support, are all barriers to adaptation to climate change (Rodriguez *et al.* 2009). The effective evaluation tools for assessing planned adaptation options, such as benefit-cost analysis is currently lacking (Hennessy 2007).

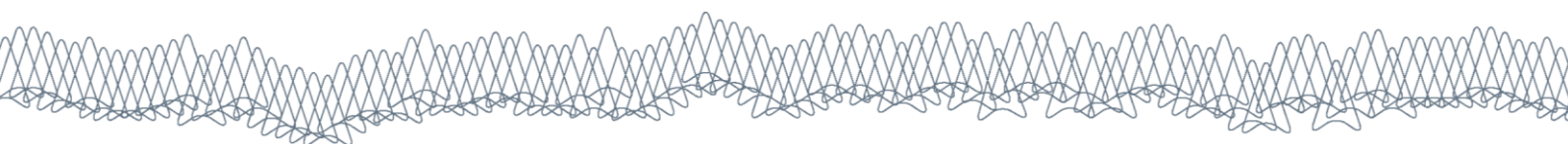
In one study Rodriguez *et al.* (2009) found that the first barrier to adoption mentioned by potential adopters was the economic factor due the costs involved in the process of adoption. So community people think that most of the climate adaptation process involved a huge investment but some adaptations are based on only the 'best practice; that they are practicing now. Potential adopters are also worried about the investment return for adaptation (Rodriguez *et al.* 2009) due to the uncertainties in climate change.

Summary and conclusions

Ecosystem services are the benefits people derived from ecosystems including the provision of food, fibre, timber and water, climate regulation, nutrient cycling, and habitat provision for biodiversity. Ecosystem services are an essential element of community wellbeing, but are under serious threat from global climate change. NRM managers in the WTC Region will be required to respond at differing temporal and spatial scale to ensure the sustainable supply of ecosystem services.

The key ecosystem services that apply to the WTC Region that will require climate adaptation pathways includes: water regulation and water provision; coastal protection and erosion control; carbon sequestration; habitat provision for biodiversity; timber production; traditional values; and marine ecosystem services.

There are many barriers to current mechanisms for effective adaptation to climate change. Current government funding for carbon offset schemes is insufficient and the gains in protection will be outweighed by the rapid loss of biodiversity. Policy



shifts are argued to be an important barrier to climate adoption since uncertainty in the direction of policies generally tends to discourage stakeholders from adopting new methodologies.

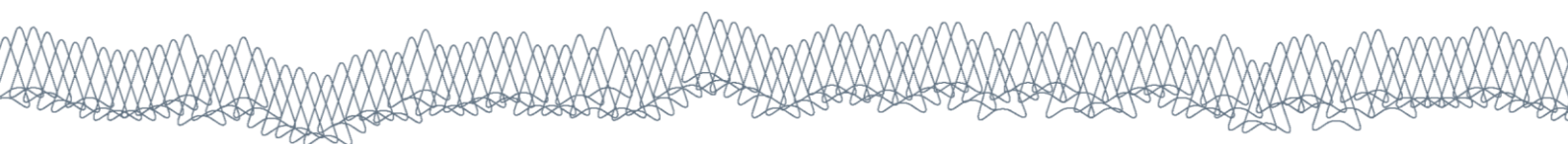
There is the need to develop appropriate mechanisms to pay for ecosystem services (PES) in the WTC Region given that they are vital for human wellbeing, are becoming increasingly limited and that many of the key services do not have substitutes. Various approaches for PES that may be applied within the WTC NRM Region have been presented and evaluated.

There is not clear evidence in the literature about the effects that a significantly low price of carbon could generate for the environment. Nevertheless, as carbon sequestration and emission avoidance projects involve high establishment costs, they are therefore highly dependent on carbon markets and prices.

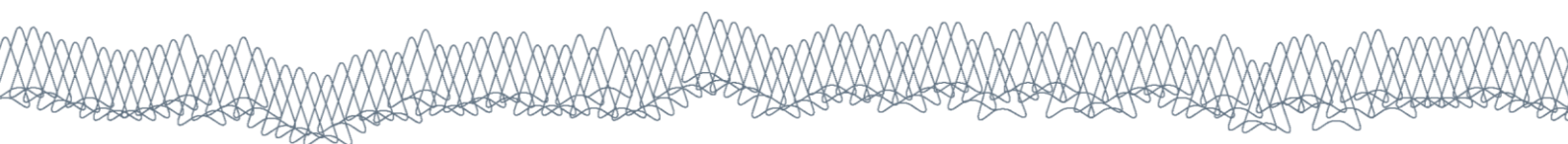
Climate change is a very long-term phenomenon and it is also very difficult to precisely predict what the future may be. Although there is a strong consensus about the climate change impacts on different ecosystem services like water provision, carbon sequestration, agricultural production and habitat provision, uncertainty exists about the level of magnitude, which also discourages the community to act to adapt with climate change in the short term. Uncertainty in climate change projections – particularly rainfall - is a barrier to climate change adaptations in Australia, including the WTC Region.

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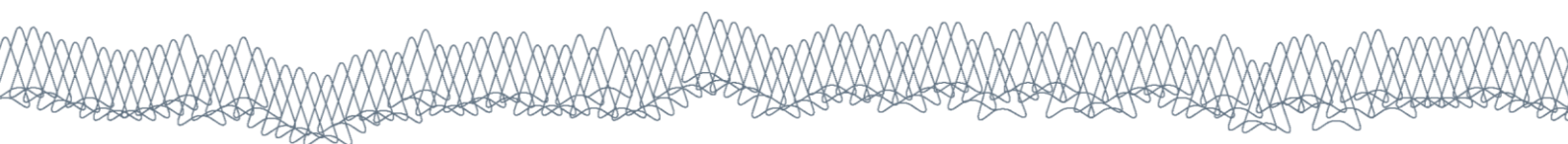
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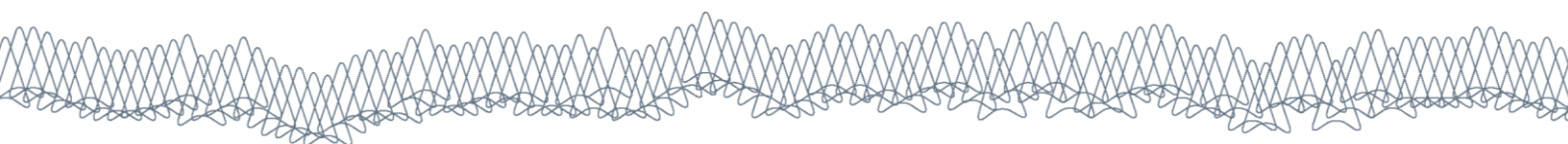
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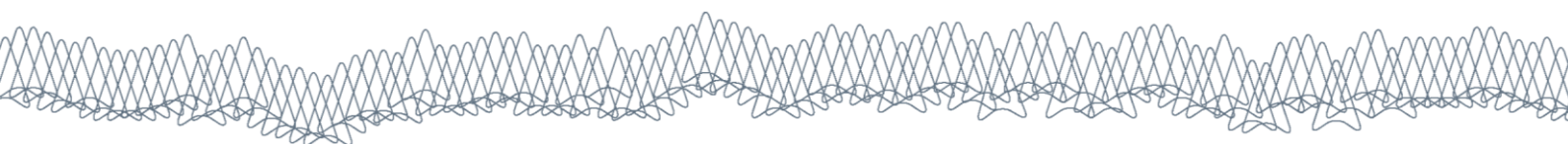
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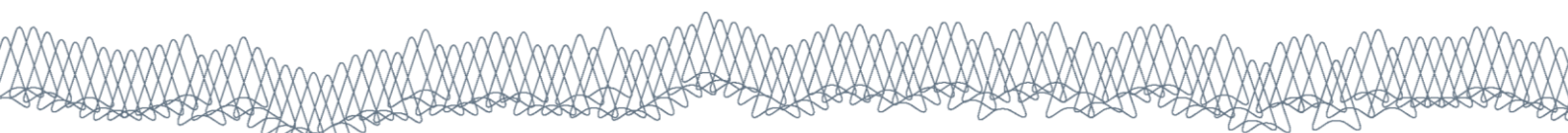
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Appendix A Priority issues for Wet Tropics Cluster Natural Resource Management groups

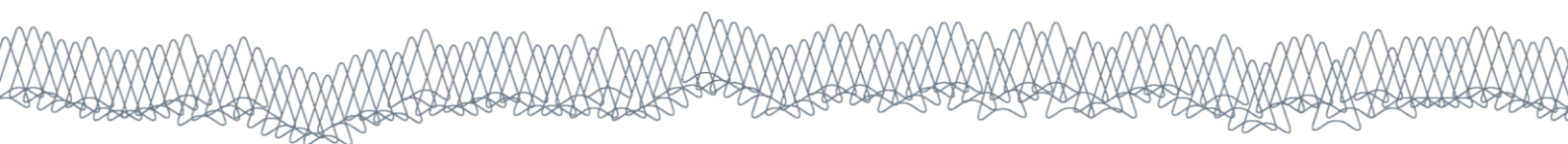
A1. Priority issues identified for previous report on impacts of climate change (Hilbert *et al.* 2014).

Physical science – Climate change projections for the wet tropics cluster

Scenarios for temperature and rainfall	<ul style="list-style-type: none"> inc. extreme high and low
Scenarios for oceans	<ul style="list-style-type: none"> sea level changes sea surface temp acidification
Implications for hydrological cycles and water quality	<ul style="list-style-type: none"> evaporation point source and diffuse water pollutants
Change in frequency of extreme weather events	<ul style="list-style-type: none"> cyclones drought flood storm surge marine intrusion erosion
Change in fire regimes	

Biodiversity

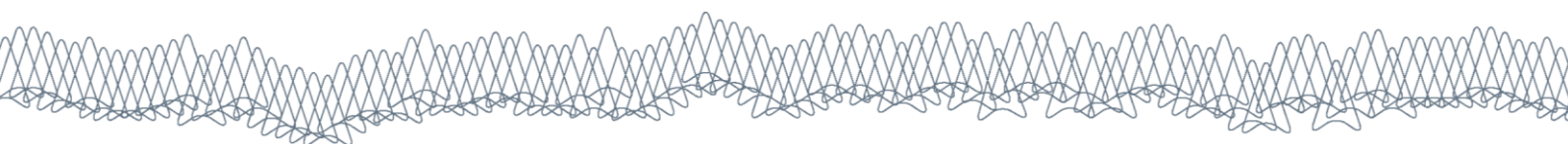
Change in distribution and abundance of invasive species	<ul style="list-style-type: none"> impacts emergent risks priorities potential adaptation responses
Change in extent and distribution of terrestrial and marine vegetation communities	<ul style="list-style-type: none"> consider water stress wetlands, seagrass, mangroves island landscapes limitations on ability to shift (e.g., altitude, coastal development) fire
Change in abundance and distribution of key terrestrial, coastal and marine species	<ul style="list-style-type: none"> esp. Turtles (distribution, heat stress, sex ratio) fish (for harvest but also higher order effects)



	<ul style="list-style-type: none"> • dugong • corals (esp. bleaching) • cassowary • endemic species • species of cultural significance • range shifts • connectivity (incl. condition) esp. migratory species • critical thresholds • impacts of extreme events • vulnerable and resilient taxa
Implication for disease	<ul style="list-style-type: none"> • Human and wildlife • vectors (mosquitoes, birds, pigs)

Socio-cultural-economic

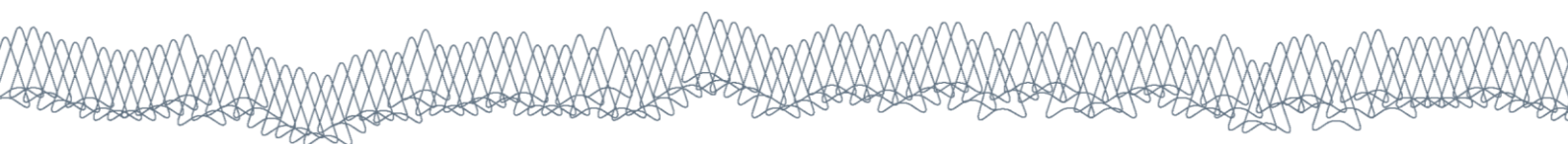
Indigenous knowledge of past climate adaptation	<ul style="list-style-type: none"> • previous land management practices • refugia • changes in systems
Impacts on Indigenous culture and livelihoods and adaptation opportunities	<ul style="list-style-type: none"> • liveability • changing resources/access (water, vegetation, key species); cultural practices • tourism (fire, cyclones, storm surge, infrastructure) • adaptation (e.g., carbon abatement/sequestration)
Impact on human infrastructure, mainland and islands	<ul style="list-style-type: none"> • sea levels • flow events • fire • cyclones • new locations and requirements
Impacts on rural and primary industries	<ul style="list-style-type: none"> • agriculture (type, scale, productivity; inc sugar cane, mining) • adaptation opportunities • realistic opportunities for carbon bio-sequestration and abatement
Ecosystem services	<ul style="list-style-type: none"> • Carbon abatement (e.g., fire management) • carbon sequestration (marine and terrestrial) • revegetation



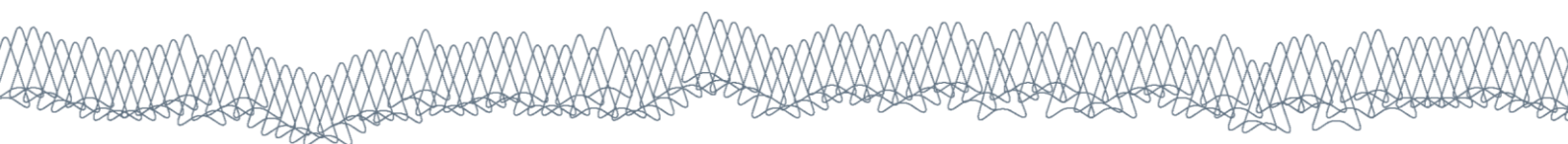
Tourism	<ul style="list-style-type: none"> • Impacts of loss of environmental values (habitats/species) • climate changes (e.g., too hot/ more frequent cyclones)
Cost benefit analysis of adaptation vs BAU	
Changes in land use patterns	<ul style="list-style-type: none"> • economic implications • social implications
Assessment of community (sectors) adaptation capacities	<ul style="list-style-type: none"> • capabilities • interests • aspirations
Changes in practices to build social and ecological resilience	

A2. Specific additional issues identified for current report on potential adaptation options.

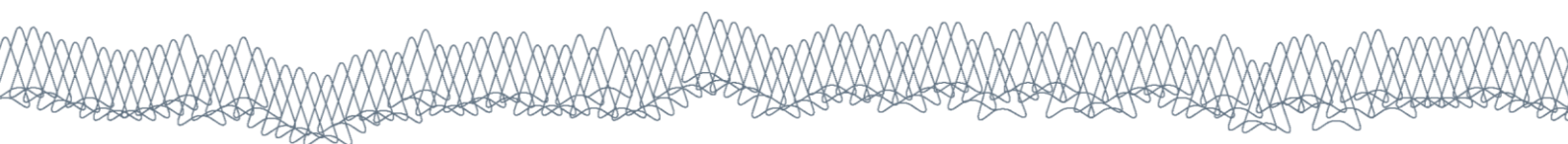
<p>Biodiversity: adaptation pathways and opportunities</p> <p>Specific taxa/ecosystems/issues:</p> <p>Turtle and Dugong</p> <p>Reef ecosystems</p> <p>Small Island ecosystems</p> <p>Lack of connectivity for movement/migration:</p> <p>Westward migration of coastal, marine, mangrove communities and dunes (SLR)</p> <p>Functional connectivity. Hard infrastructure, urban development, roads, farmland preventing restoration of connectivity; Where will translocation be important?</p> <p>Fire management to maintain ecological integrity given changed fire conditions</p> <p>Reproduction in vegetation communities (inc.temp and rainfall shifts may alter germination conditions); any available strategies to maintain microclimates?</p> <p>Adaptation pathways for integrated weed management (environmental and agricultural; note herbicide resistance). In MWI region, current priority weeds addressed in pest management strategy (avail. On request). Specific weeds that will become problems; early detection and intervention program</p> <p>Need to shift from maintenance of pre-European systems to enabling adaptation to at least 2 deg. Warming</p> <p>Quantified trigger points , e.g., Eungella rainforest will degrade with 1.5 deg rise; increased fire risk in coastal veg with 2 deg rise; increased evaporation will reduce avail freshwater resources by 5% for every deg of temp rise.</p> <p>Local, regional, national, international examples/case studies</p> <p>Key considerations/principles for monitoring whether particular actions have intended adaptation outcomes</p> <p>Barriers to potential adaptation actions (e.g., social/political/ economic). Potential strategies to surmount barriers or enable adaptation actions.</p>
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<p>Ecosystem services: adaptation pathways and opportunities</p> <p>Specific ecosystem services: Coastal Protection and erosion control Carbon sequestration Nursery habitat for marine species More definitive info about ecosystem services relevant to the cluster or NRM regions Mechanisms for establishing payments for ecosystem services What if carbon is worth a lot less? Implications for environmental versus carbon offsets Key considerations/principles for monitoring whether particular actions have intended adaptation outcomes Barriers to potential adaptation actions (e.g., social/political/ economic). Potential strategies to surmount barriers or enable adaptation actions.</p>
<p>Infrastructure: adaptation pathways and opportunities</p> <p>Specific elements of infrastructure/service provision: Maritime services infrastructure Energy generation and supply Housing What types of clean energy suit the cluster region (e.g., cloudy not good for solar) Options for soft versus hard infrastructure in adaptation, including comparative economics Novel ways to capture and store water for ag and urban (e.g., evaporation from dams) Potential for adaptation measures to cause (more) environmental damage (e.g., weirs, bund walls (seawater intrusion), rock groynes (sand erosion) Local, regional, national, international examples/case studies Key considerations/principles for monitoring whether particular actions have intended adaptation outcomes Barriers to potential adaptation actions (e.g., social/political/ economic). Potential strategies to surmount barriers or enable adaptation actions.</p>
<p>Industry: adaptation pathways and opportunities</p> <p>Specific industries: Fisheries How to engage industries in acknowledging there is a problem? Reducing methane emissions not an economically viable option for extensive cattle grazing The potential for climate change to specifically impact rural best management practices/principles, especially where they are based on more precision techniques. What is the possibility that precision-based techniques might increase vulnerability of farmers? Local, regional, national, international examples/case studies Key considerations/principles for monitoring whether particular actions have intended adaptation outcomes Barriers to potential adaptation actions (e.g., social/political/ economic). Potential strategies to surmount barriers or enable adaptation actions.</p>



<p>Indigenous communities, livelihoods & knowledge: adaptation pathways and opportunities</p> <p>Specific communities/ aspects: Building general community resilience Building sustainable local economies Identifying key drivers of change to culture Identifying what aspects of community culture support adaptation and what aspects of culture impede adaptation Improving cultural knowledge integration into policy, landuse and land management decisions Local, regional, national, international examples/case studies Key considerations/principles for monitoring whether particular actions have intended adaptation outcomes Barriers to potential adaptation actions. Potential strategies to surmount barriers or enable adaptation actions.</p>
<p>Social impacts: adaptation pathways and opportunities</p> <p>Specific aspects/ locations/ industry sectors: Impacts and role of women in climate change and adaptation Impacts of technology Will climate change be likely to change the desirability of the WTC region to live? If so, by how much? Is climate change likely to change the population carrying capacity for the WTC region? If so, by how much? Local, regional, national, international examples/case studies Key considerations/principles for monitoring whether particular actions have intended adaptation outcomes Barriers to potential adaptation actions (e.g., social/political/ economic). Potential strategies to surmount barriers or enable adaptation actions.</p>
<p>Integration of adaptation pathways and opportunities across sectors</p> <p>What is the comparative economics of no adoption versus early or late adoption if adaptation across biodiversity, industry, infrastructure impacts etc?</p>
<p>Emerging NRM planning frameworks</p> <p>Local, regional, national, international examples/case studies Barriers to potential adaptation actions (e.g., social/political/ economic). Potential strategies to surmount barriers or enable adaptation actions.</p>
<p>Evolving adaptation methodologies and tools</p> <p>Evaluating different adaptation pathways (principles, criteria, approaches) Barriers to potential adaptation actions (e.g., social/political/ economic). Potential strategies to surmount barriers or enable adaptation actions.</p>



Specific communities/aspects building general community resilience building sustainable local economies identifying key drivers of change to culture identifying what aspects of community culture support adaptation and what aspects impede adaptation improving cultural knowledge integration into policy, landuse and land management decisions
Local, regional, national, international examples/case studies
Key considerations/ principles for monitoring whether particular actions have intended adaptation outcomes
Barriers to potential adaptation actions. Potential strategies to surmount barriers or enable adaptation

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